The influence of drilling process automation on improvement of blasting works quality in open pit mining

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Abstract. The article describes the monitoring system of blasthole drilling process called HNS (Hole Navigation System), which was used in blasting works performed by Maxam Poland Ltd. Developed by Atlas Copco's, the HNS system – using satellite data – allows for a very accurate mapping of the designed grid of blastholes. The article presents the results of several conducted measurements of ground vibrations triggered by blasting, designed and performed using traditional technology and using the HNS system and shows first observations in this matter.

1 Introduction

Currently in the world mining industry, modern mines use technologies that allow for remote control, automation and navigation of heavy machines. Manual control in this type of machines nearly reached excellence thanks to hydraulic and electrohydraulic joysticks application. Machine automation in the mining industry allows for the precise drilling of the blastholes, which results in more uniform fragmentation and consequently for reduction of operating costs [1].

In 2016, Maxam Poland Ltd., which provide the blasting service for opencast mining, have purchased the Atlas Copco SmartROC T45 drill rig (Fig. 1) to raise the competitiveness of the company on the market. The drill rig has been equipped with the total-site Hole Navigation System based on the Global Navigation Satellite System (GNSS) to ensure all holes are drilled precisely parallel to each other. GNSS-guided drilling is accurate to within 10 centimeters and automatically calculate its depth to the given elevation [2].

In spite of the use of high-tech machines, the quality of the blasthole drilling, according to designed drilling and firing patterns, largely depends on experiences and skills of operator. Precisely drilling of the holes permit optimized blasting patterns while maintaining control of fracture size, fly-rock and ground-borne vibrations, contributing to reduced costs [3].

The vibrations induced by blasting operations in opencast mining have been analyzed in a number of research works [3-6]. The results of measurements and observations have

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proved, that some factors may affect their intensity, including the distance from the blasting site, geological structure of the rock mass, the amount of explosives used and applied delays.

The results of measurements of ground-borne vibrations induced by blasting have been analyzed within the framework of presented paper. Two different methods of blasthole drilling were considered, i.e. using the HNS system and traditional drilling method. The tests were carried out in selected opencast mine in Poland, in which blasting service is provided by Maxam Poland Ltd.

2 Hole Navigation System

The idea behind the application of the HNS system is to support the process of determining the position of the drill rig and the designed blastholes using correction data, e.g. ASG-EUPOS system (EUPOS Active Geodetic Network). To generate a stream of observations and/or adjustments based on data from the group of ASG-EUPOS stations, the computing system must have approximate user position information, which uses the Leica GNSS receiver fitted to the drill rig (Fig. 1).

Fig. 1. SmartROC T45 drill rig with a GNSS Leica receiver [7].

This receiver sends information on its position to the computation module on the ASG-EUPOS server. In response to the approximate position of the user, the ASG-EUPOS computation module generates a stream of correction network data and sends it to the receiver in the drill rig. Communication between the computation module on the support service server and the receiver module on the drill rig is carried out through the GSM network. In addition to the use of the ASG-EUPOS service, the user must also be able to use data transmission in the GSM network from one of the local mobile network operators that provides network coverage at the place of machine operation. Lack of permanent access to the cellular network will prevent transmission of data between the drill rig and the ASG-EUPOS computation module and the transmission of correction data, thus precluding the use of the HNS system on the drill rig [7]. The drilling pattern is designed in the ROC Manager software, which is part of the HNS system. It allows for analysis of the data obtained during drilling of blastholes using the Measuring While Drilling (MWD) technology (Fig. 2). In addition, the system enables the tracking of drilled blastholes and their deviations.

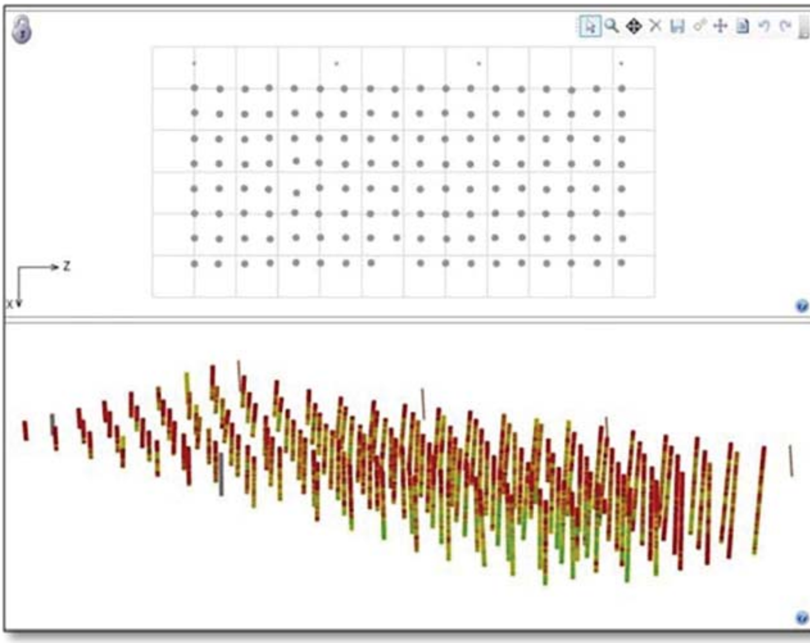

Fig. 2. Location of the drilled holes using the MWD data, generated in the ROC Manager software [7].

The HNS system collects data based on sensors located on the drill rig platform. By assigning colours to numerical values (e.g. rock hardness), the user can trace their variations at each meter of the blasthole. The ROC Manager uses the GPS coordinates of the two reference points that have been set by positioning the drill mast with the GNSS receiver mounted above them. The mapping of the blasthole grid in the 3D space, with no support tools, is both cumbersome and time-consuming. So far, the mapped drilling and firing patterns have shown a view of the holes in two planes. Incorporation of vertically deviated blastholes in the drilling pattern plan have caused problems in maintaining the appropriate spacing between them, especially in the bottom section, which in turn led to uneven distribution of the explosives in the blastholes. Currently, thanks to the Hole Navigation System, the drilling machine operator receives a digital pattern layout, which is exported into the computer memory of the drill rig. The design of drilling pattern takes into account the complex geometry of the slope and the spatial orientation of the blastholes, eliminating errors at the design stage.

The blasthole drilling process is almost fully automated, thus the human factor is reduced, i.e. the errors of the drilling machine operator. Drilling of the individual hole is carried out up to the set level ordinate, taking into account the subdrilling and the frequent denivelations of the floor, on which the drill rig is travelling. So far, during drilling operations, many attempts were made to obtain the exact hole lengths specified in the blasting pattern layout, which, in the case of complicated grids, could lead to incorrect performance of subdrilling. One of the example of blasting works design and control using the HNS system, which was aimed at access pit execution is presented in Figures 3 to 5. The views of the designed and performed blastholes were generated in the ROC Manager software.

In this case, determination of blasthole grid in a conventional way would take approximately 2 hours. Determining of the same grid by the use of HNS system takes not more than 15 minutes. By changing the final ordinate level of each rows of holes, the access pit to the next level can be performed with very high accuracy (each row of holes which is drilled 30 cm deeper, in case of 3-metre spacing between the rows, gives the slope inclination of 1:10, i.e. 6º). Accurate determination of hole lengths with the precise subdrilling results in regular surface of the floor with a simultaneous optimization of fuel consumption (additional unnecessary metres = additional fuel consumed) and finally – reduce the drilling time.

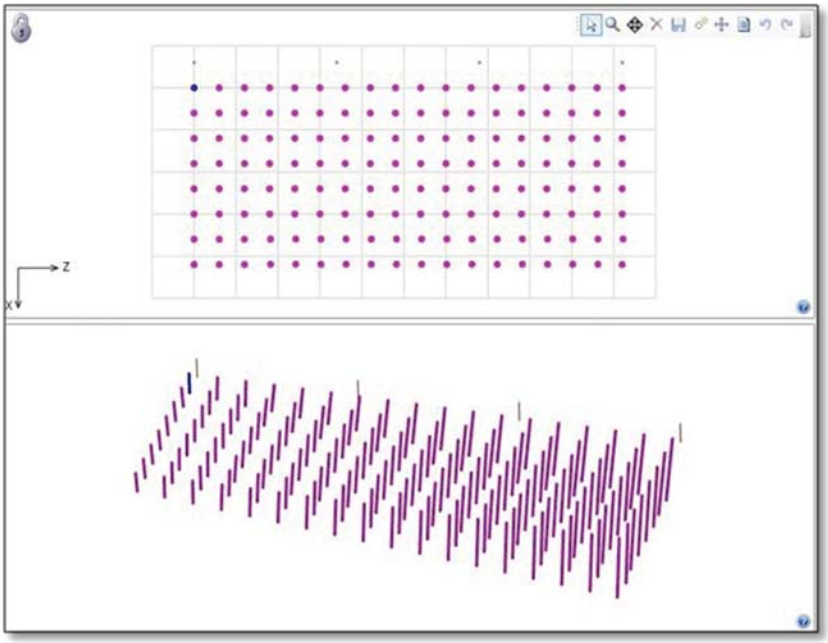

Fig. 3. View of the designed blasthole grid for an access pit [7].

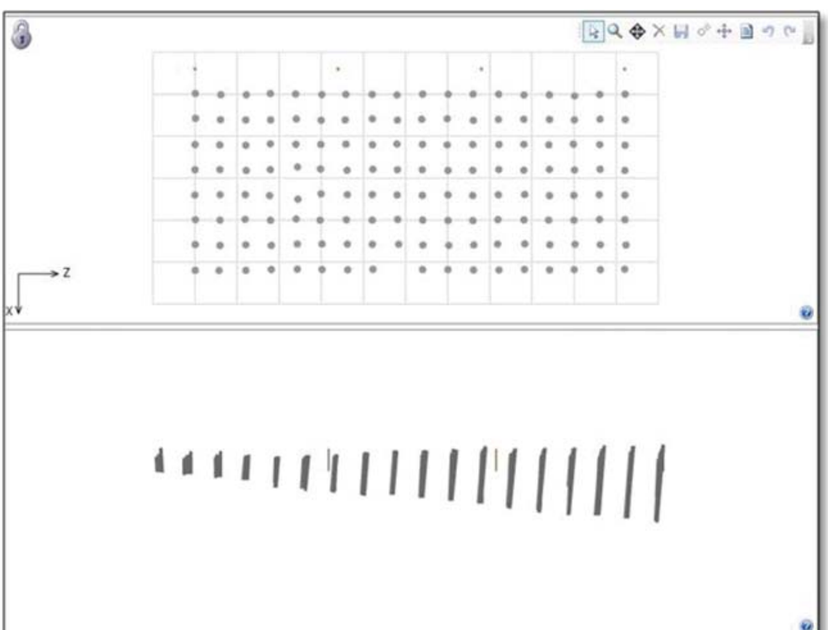

Fig. 4. Locations of drilled blastholes for an access pit [7].

Fig. 5. View of the access pit at the mine site prior to firing [7]

The length of the subdrilling is determined by the experts during the measurements of the range of paraseismic vibrations and the determination of the maximum co-operating explosives charges [8]. One of the reasons of increased vibration is incorrect performance of subdrilling. Up until now, inaccurate drilling of the holes, mainly in the bottom section, has generated the stumps above the theoretical grade and has increased levels of ground vibrations. By selecting the right mining method and appropriate drilling and firing patterns, the size of the ground vibrations can be controlled and finally reduced. After the first tests of the HNS system, the decrease of ground vibrations caused by rock blasting was observed. For that reason, an analysis of the influence of the correct drilling of the holes on the level of paraseismic activity has been developed.

3. Seismic analysis

So far, a number of research works were made to determine the impact of the drilling accuracy on the quality and effectiveness of blasting works in both open-cast and underground mining. In the case of underground mining, an increase of the round during the attempts of the Feeder Guiding System (FGS) implementation was observed. This was possible by controlling the correctness of the work with respect to the internal procedures, i.e. drilling of the blastholes according to the applied drilling and firing pattern and obtaining the required quantity and length of the holes. The trials have also showed the improvement of blasting works efficiency in terms of the rock fragmentation [9].

The technology of designing and performance of blasting operations in opencast mining is significantly different from blasting in underground mining. One of the aim of underground blasting, apart from throwing rocks away, is to distress the rock mass by amplifying the elastic wave caused by detonation of explosives, which is one of the main elements of active rockburst prevention method. In the opencast mining, the ground vibration induced by detonation of explosives is undesirable because it is energy loss which could have negatively influences the technical condition of the buildings and other constructions located in the vicinity of blasting works area. That means that the drilling and firing pattern should be designed according to the expert's guidelines. The analyses on the ground vibrations generated by blasting have been developed and examined by many researchers. It follows that the observed paraseismic activity is influenced by many factors of geological, mining and technological nature. The most important include [3, 4]:

- quantity of explosives and number of co-operating charges,

- type of explosive used,
- blastholes geometry (including the length and spacing of holes),
- type of initiation (instantaneous or milli-second detonators),
- applied delay time,
- physical and mechanical properties of the rock mass,
- the distance from the blasting site.

In order to preserve the admissible values of ground vibrations, appropriate performance of the drilling grid, in accordance with the designed drilling and firing pattern, which consider the recommendations of experts is required. Previous mining experiences and earlier research done in this field have proved, that insufficient accuracy of the drilling grid performance will be reflected in the level of ground vibrations [3, 4, 10]. And thus, it will be possible to determine the impact of the automation of the drilling process on the final effect of blasting operation. Considering the above, in order to draw reliable conclusions from the comparative analysis, the number of variables should be reduced and investigated in similar geological and mining conditions, which determines the selection of given explosive type and the geometric parameters of the blasting works (e.g. size of burden, subdrilling and hole spacing). These parameters are related in turn with selection of the column charge construction and its size. It is commonly assumed that these parameters are constant during the study in a particular location. Therefore, two following variables should be determined: the weight of the co-operating charge (Q) and the distance of the measuring point from the blasting site (r). Vibration intensity (velocity of vibration [mm/s]) at the measuring point can be calculated from the following relationship:

$$v = k \cdot Q^{\alpha} \cdot r^{-\beta} \tag{1}$$

where:
k – coefficient characterizing geological conditions and parameters of blasting works,
r – distance of the measuring point from the blasting site,
Q – weight of explosives per co-operating charges.

During the control tests carried out by experts, the specific charge should be obtained. It may be calculated from the following relationship:

$$\rho = \frac{Q^n}{r} \tag{2}$$

where: $n = \alpha / \beta$.

Unknown parameters of the equation (1) are: coefficient k and exponents α and β. They are obtained during the control tests aimed at determining the maximum explosive charge per one delay (co-opearing charge) and permitted levels of ground vibrations.

Measurements of the ground vibrations levels induced by detonation of explosive charges were carried out in one of the Polish granite mines. Conducting the measurements in a specific zone allows to investigate the seismic activity triggered by blasting works of similar parameters, i.e. the maximum co-operating charge weight, total charge (Q), the initiation method and the blastholes geometry. Monitoring of the vibration velocity was made using the pocket size multi-channel vibration instrument called Vibraloc (Fig. 6). It is tri-axial geophone integrated in one device. Accuracy is equal +/- 5 % for vibration velocity from 1 to 240 mm/s in the frequency range 15÷250 Hz [11]. The following set up was used during survey:

- Sampling frequency - 4000 Hz
- Trigger level - 0,5 mm/s (for all channels L, T, V).

Device was installed on the ground (from 200 to 600 m from blasting point) by means of three anchors for good connection between device and soil. Figure 7 shows an example plot of the velocity of ground vibrations generated by the Vibraloc system.

Fig. 6. Vibraloc instrument

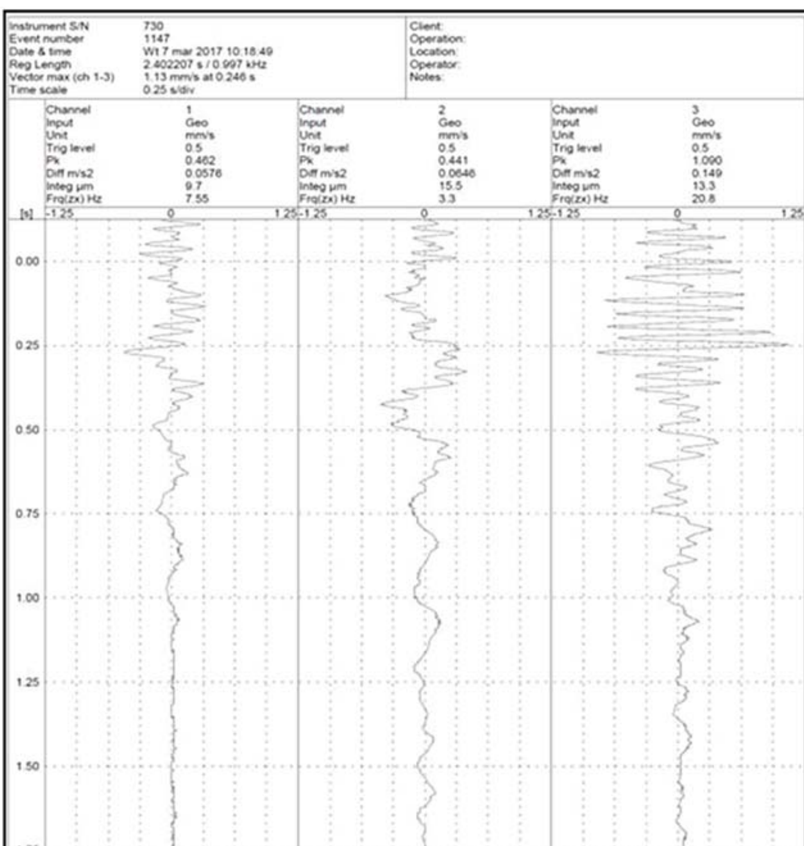

Fig. 7. An example plot of the velocity of ground vibrations from the measurement of 7 May 2017

The velocities of vibrations generated by blasting works, which were designed and performed using the HNS technology (variant I) and using the conventional method (variant II) were analyzed. Each case consisted of 7 series of blasting. Drilling and firing patterns for individual blasting works were similar. It was determined by the geological and mining conditions of the mine site. The blasting parameters and the total volume of the explosives were consistent with the mining technology currently used in that mine. The selected parameters of the blasting works carried out within the framework of presented analysis for both variants are presented in Table 1. The schematic diagram of the charge construction in an explosive column, as well as the blasthole spacing are shown in Figure 8.

Table 1. Selected blasting parameters considered in analysis.

Parameter	Symbol	Unit	Blasting with HNS system (variant I)	Conventional blasting (variant II)
Bench height	H	m	16.3÷15.8	14.0÷15.5
Hole depth	l	m	17.3÷16.8	15.0÷16.5
Subdrilling	p	m	1.0	1.0
Stemming	b_p	m	2.5	2.5
Intermediate stemming	l_{pp}	m	-	1.0
Burden	z	m	3.3	3.0
Distance between holes	a	m	3.8	3.8
Distance between rows	b	m	3.0	3.0
Hole inclicantion	α	degrees	83÷88	83÷88
Diameter of the blasthole	Φ	mm	89	89
Number of blastholes	n	szt.	42	30
Number of rows	i	szt.	4	2
Charge weight per delay	Q_z	kg	120	110
Charge weight per hole	Q_o	kg	120	110
Total charge	Q_c	kg	3991	3120
Connector delay	-	ms	25, 42, 67	25, 42, 67

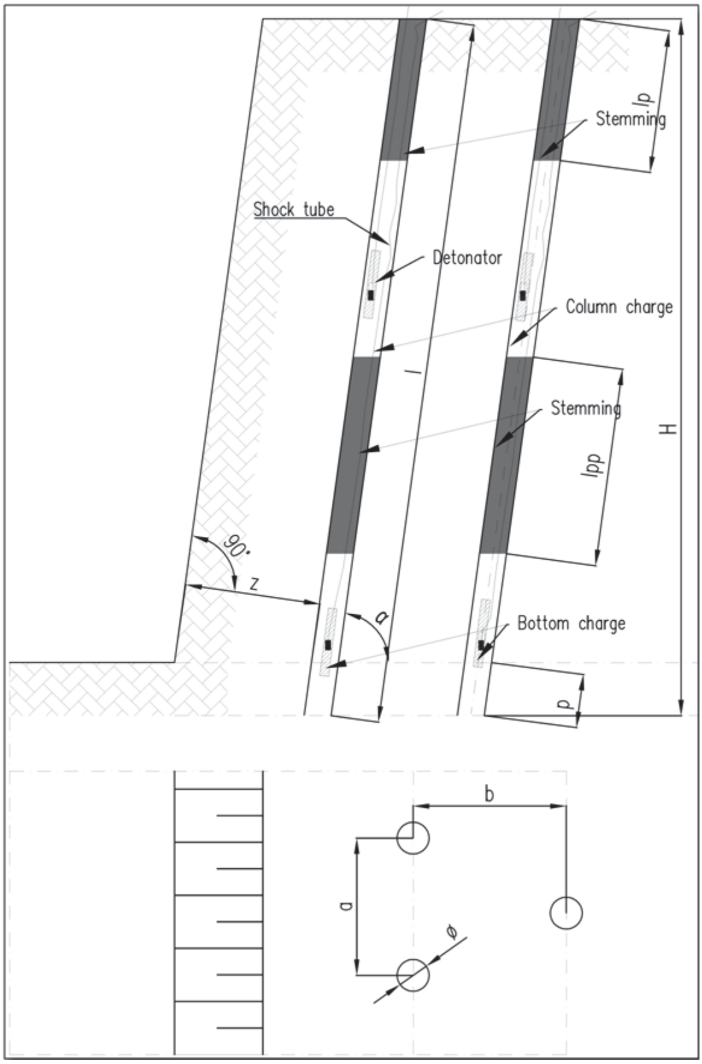

Fig. 8. Geometrical parameters of the blasting grid and construction of an explosive charge

The mathematical propagation model of ground vibration (1) was determined based on the studies of the range of the vibration impact on the surrounding environment in the vicinity of the analyzed granite mine. This research was carried out by the Poltegor Opencast Mining Institute. It has allowed to calculate the maximum specific charge (6), the predicted charge (4) and the charge calculated on the basis of the values of vibration velocity (5). Specific charge allows for the comparative seismic analysis (7) for selected blasting configurations differing in the volume of the charge *Q* and the distance of the measuring point from the vibration epicentre. For analysis of the vibration propagation, the following formulas were used [3]:

- propagation equation

$$v = k \cdot \rho^{\beta} \; [mm/s] \tag{3}$$

k ,β – coefficient and exponent, which are dependent on the geological and mining conditions and are determined experimentally,

ρ – specific charge.

The predicted specific charge, calculated from the blasting works parameters (quantity of explosive charge and the distance of the measuring point from the vibration epicentre) according to the following relationship:

$$\rho_{rk/rhns} = \frac{Q^{1/\beta}}{r}\,[kg/m] \tag{4}$$

where:
β – exponent, equal 2 for local geological and mining conditions [6][7],

$\rho_{rk/rhns}$ – predicted value for the variant with conventional blasting ρ_{rk} and designed and performed using the HNS system ρ_{rhns} determined on the basis of the blasting works parameters (e.g. explosive charge) and the distance of the measuring point from the blasting site. This value should be lower than admissible charge ρ_{dop}.

Specific charge calculated from the results of measurements:

$$\rho_{k/hns} = \left(\frac{v_{zxy}}{k}\right)^{1/\beta}[kg/m] \tag{5}$$

$\rho_{k/hns}$ – the value calculated from the measurements, for the variant with conventional blasting ρ_k and variant designed and performed using the HNS system ρ_{hns} determined from the relationship (5) by applying propagation equation parameters (3) and measured vibration velocity. The value of this parameter should be less than or equal $\rho_{rk/rhns}$ and consequently also less than ρ_{dop}.

The admissible specific charge, calculated on the basis on the propagation equation and acceptable vibration velocity:

$$\rho_{dop} = \left(\frac{v_{dop}}{k}\right)^{1/\beta}[kg/m] \tag{6}$$

Finally, the volume of specific charge can be represented in the form of following inequality:

$$\rho_{dop} \geq \rho_{rk/rhns} \geq \rho_{k/khns} \tag{7}$$

Afterwards, all calculated values of specific charge ρ have been averaged and compared to each other. Direct comparison of the specific charge calculated for the variant of the HNS system (variant I) ρ_{khns} with the specific charge calculated for the variant of the conventional blasting (variant II) ρ_k would be unreliable, because the individual blasting operations differed in the volume of the total charge (Q) and the measuring points were located at different distances from the blasting site (r). Figure 9 shows, that the predicted value of specific charge for the blasting works performed using the HNS system ρ_{rhns} is equal to the predicted value for the second variant ρ_k. Thus, the differences between the measured values $\rho_{k/khns}$ and predicted values $\rho_{rk/rhns}$ should be taken into account. Increasing the difference between the triggered value ρ_{khns} and the predicted value ρ_{rhns} compared to the difference for variant II, provides information on the reduction of seismic activity. The results of the measurements are presented in Table 2.

Table 2. Results of vibration velocity measurements with corresponding specific charges for both analyzed variants.

Type of blasting and number of test		*Q* [kg]	*r* [m]	v_{zxy} [cm/s]	$\rho_{rk/rhns}$ $[kg/m]$	$\rho_{k/khns}$ $[kg/m]$
Blasting with HNS system (variant I)	1	130	300	0.113	0.0380	0.0221
	2	120	300	0.103	0.0365	0.0214
	3	111	400	0.056	0.0263	0.0173
	4	125	600	0.124	0.0186	0.0229
	5	120	300	0.096	0.0365	0.0209
	6	110	300	0.083	0.0350	0.0199
	7	130	300	0.088	0.0380	0.0203
Conventional blasting (variant II)	1	110	260	0.227	0.0403	0.0283
	2	120	300	0.136	0.0365	0.0236
	3	115	200	0.47	0.0536	0.0365
	4	120	300	0.385	0.0365	0.0340
	5	130	280	0.641	0.0407	0.0407
	6	125	370	0.31	0.0302	0.0315
	7	110	200	0.626	0.0524	0.0404

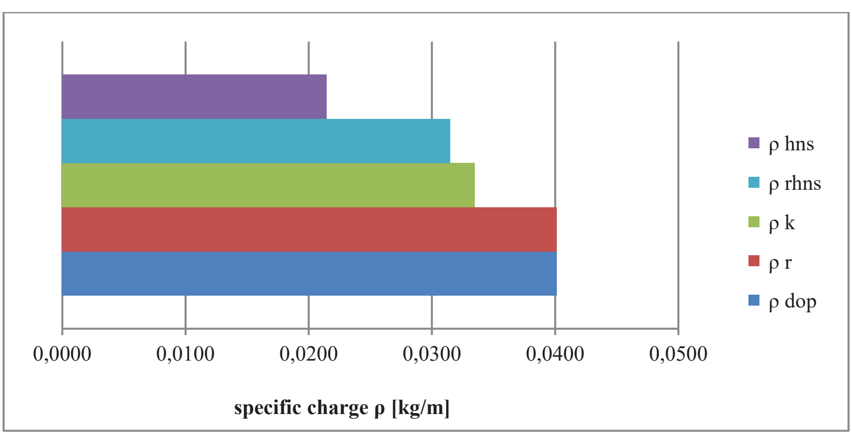

Fig. 9. Graphic analysis of the results of comparative tests of the blasting using the HNS system (ρ_{hns}, ρ_{rhns}) with conventional blasting (ρ_k, ρ_r).

4. Summary

The results of the measurements of ground vibrations triggered by blasting works, despite a small amount of obtained data, show a significant difference in level of specific charge and measured vibration velocities depending on the technology used. Individual vibration measurements were carried out in almost identical mining and geological conditions and at a similar distance from the source of vibration, so that the results could be considered as reliable.

The average value of the specific charge, depending on the measured vibration velocity, in this specified place and situation is approximately 30% lower than the predicted value for variant I. In contrast, the level of specific charge in conventional blasting (variant II) is approximately 20% lower than the predicted value, so the drop in the triggered seismic activity when using the HNS system is noticeable. Figure 10 shows the relationships between the vibration velocity and the predicted specific charge value for each of the analyzed variants.

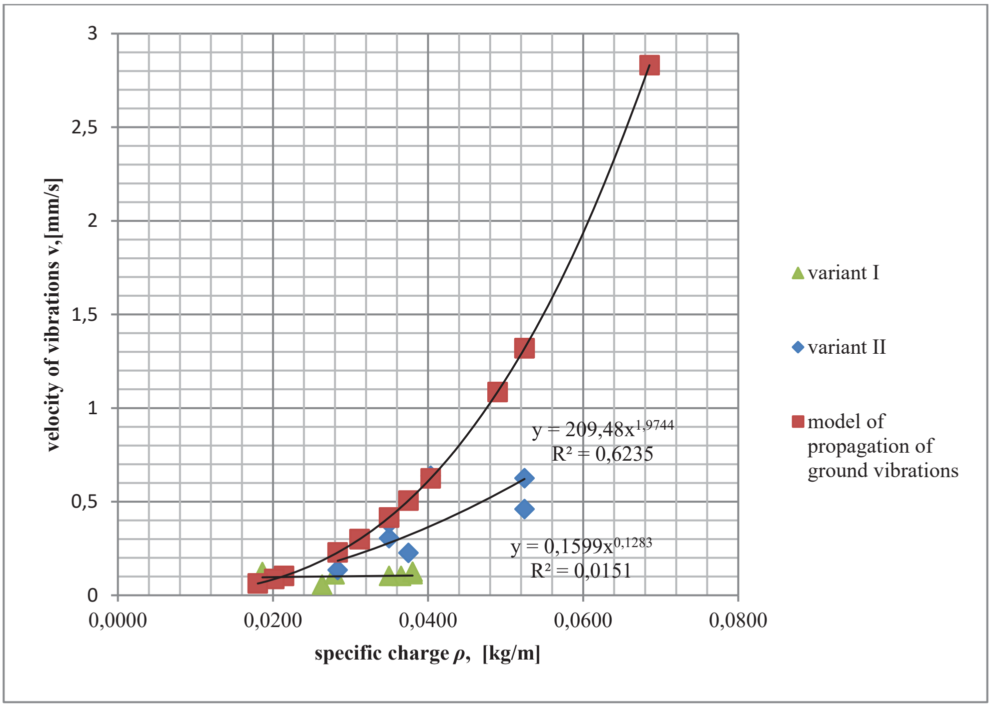

Fig. 10. Graphic analysis of the comparative studies results of vibration velocity as a function of specific charge.

Research work in the aspect of the impact of the blasthole drilling process quality on the final result and effectiveness of blasting works should be continued by expansion of the scope of measurements. Determination of the degree of rock fragmentation from a blast using the HNS system and methods based on conventional drilling seems to be crucial from the point of view of the blasting works effectiveness.

The observed drop in seismic activity when using the HNS system is associated with the maintenance of suitable subdrillings and the uniform distribution of explosives in the blastholes, particularly in the bottom section, which was problematic in the conventional drilling method. Reducing the paraseismic activity in the near future may contribute to a change in the vibration propagation pattern and, as a result, to the increase of the admissible charge weight per delay and total charge, which will directly translate into a reduction on operation costs of mining works. This paper shows preliminary observation of influence of

HNS system usage on inducted vibration and more research is needed to obtain more accurate data in this subject.

This work was financed by the Grant no. 0401/0128/17.

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