Novel method of multi-face destress blasting efficiency assessment

Krzysztof Fuławka
KGHM CUPRUM Ltd. R&D Centre, Poland

Piotr Mertuszka
KGHM CUPRUM Ltd. R&D Centre, Poland

Marcin Szumny
KGHM CUPRUM Ltd. R&D Centre, Poland

Lech Stolecki
KGHM CUPRUM Ltd. R&D Centre, Poland

Izabela Jaśkiewicz-Proć
KGHM CUPRUM Ltd. R&D Centre, Poland

ABSTRACT: In this paper, the newly formulated solution of multi-face destress blasting efficiency assessment is presented. The developed method is relevant for near and far-field effect evaluation and is improved by the duration, amplitude, and frequency characteristics of blast-induced seismic waves. The proposed approach is based on the advanced analyses of the waveforms generated by blasting, ground motion prediction equations and data describing the technological parameters of blasting in terms of the amount of explosives, delay times, and spatial location of mining faces. The proposed solution was validated in deep underground mines in Poland in which the room-and-pillar mining method is applied. Based on the performed analysis, it is shown that a new method may be used as an element of rockburst hazard control in underground mines. However, the developed method may also be successfully implemented in other engineering practices, including open pits and quarries.

Keywords: Destress blasting, seismic waves, blasting efficiency, mining seismology, underground mining.

1 INTRODUCTION

According to recent studies, destress blasting is the most effective solution in terms of rock mass preconditioning (Konicek et al. 2011 and Vennes & Mitri 2017). The main goals of destress blasting are:

- generating cracks of the rock mass in the vicinity of blasting operations (Kan et al. 2022);
- reduction of friction on the slip surface of faults and cracks existing in the rock mass, which may trigger a mining tremor (Fuławka et al. 2022).

Therefore, regardless of the actual effect, the main purpose of destress blasting is the preconditioning of the rock mass, preventing further accumulation of energy and, in exceptional cases, causing a seismic event in the vicinity of the mining field while the mining crew is outside an endangered area. Such technique has been practiced and developed for years in Polish underground copper mines, where explosives are used for both ore extraction and destressing purposes. Because deposit in these mines is excavated with the use of a room-and-pillar mining system, the destressing impulse is generated by the simultaneous firing of explosives in a dozen or several dozens of mining faces within one mining panel. Due to the scale of mining, which can be described by about 500-700 faces and over 60 tons of explosives detonated every day, this method is considered the most effective tool for active rockburst prevention in the conditions of Polish copper mines (Caputa & Rudziński 2019). However, it should be noted that in order to ensure maximum efficiency of blasting works, it is necessary to carry out the periodical evaluation of blasting efficiency, which is the basis for further improvement. Still, until recently there was no avaliable method for reliable multi-face destress blasting efficiency evaluation.Within this paper, a novel method of destress blasting efficiency evaluation is presented. This method allows to analyse if the seismic impulse generated by the number of simultaneously detonated faces is sufficient considering the number of faces, amount of explosives, the distance between the area of interest and subsequent mining faces, and blasting patterns applied during the firing of mining faces. Moreover, seismic effects with the use of a novel method may be analysed not only in terms of amplitude distribution but also including the duration of the vibrations and their dominant frequency, which is definitely an innovative approach.

2 MATERIAL AND METHODS

The analysis was performed for one of the mining panels characterized by a high level of seismic activity. Within the framework of this research, waveforms of 60 multi-face blastings were used for the determination of empirical constants and development of ground motion prediction equations. After that, another 61 blastings were analyzed in terms of generated seismic effect. In the analysed cases from 1,300 kg up to 4,400 kg of explosives were fired simultaneously using 10 up to 40 faces during a single destress blasting.

2.1 Description of the site

Within the analysed area the direct roof of the excavations is mainly formed of dolomite. The thickness of this stratum is 11 m, on average. Above them, there are anhydrites with a thickness of 34 m to 96 m. Above the anhydrites there is a layer of rock salt with a thickness of 32 m to 133 m. In the floor of the excavations, there are sandstones with a thickness of about 8–9 m. The deposit in the analysed area is located at a depth of 977–1,093 m below ground level and is inclined approx. 2-3° towards the NEE. The situational plan of the analysing mining panel is presented in Figure 1.

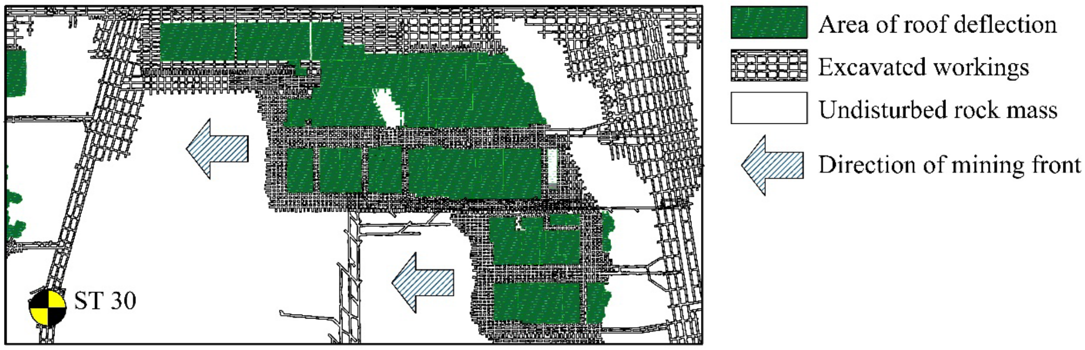

Figure 1. Situation map of the analysed mining pannel.

2.2 Seismic measurement and data processing

Seismic monitoring posts are equipped with three perpendicularly placed single-axis Willmore MK IIIA seismometers. The flat characteristic of recordable frequencies for these devices is in the range of 0.1-150 Hz. It must be born in mind that collected waveforms in raw form are distorted by electrical noise as well as noise generated by the ventilation system. This type of signal contamination has a relatively constant dominant frequency of around 50 Hz (electrical interference). Therefore, waveforms were filtered in the range of 1-50 Hz using the second-order Butterworth bandpass filter which is commonly used to process high-frequency seismic data (Li et al. 2020).

2.3 *Calculation of blasting efficiency factor –* B_{EF}

The generalized form of the indicator B_{EF} is as follows:

$$B_{EF} = E_{SA} \cdot E_t \cdot E_f \tag{1}$$

E_{SA} – amplitude-based component; E_t – time-based component; E_f – frequency-based component.

The effectiveness of group destress blasting in terms of amplitude distribution can be determined by the formula:

$$E_{SA} = \frac{PPV_{max}}{PPV_{R0}+S} = \frac{PPV_{max}}{K \cdot (R_0)^{\beta}+S} \tag{2}$$

PPV_{max} – the maximum recorded amplitude of a seismic wave induced by detonation of a group of faces, PPV_{R0} – the estimated value of the maximum vibration amplitude of the seismic wave induced by the detonation of the cut in faces characterized by the highest value of the coefficient R_0, S – factor indicating a local tendency to amplification/attenuation of the seismic wave depending on the number of simultaneously detonated faces.

As noted by Nicholls et al. (1971) and Mutke et al. (2016) the estimation of PPV_{R0} may be done with the use of the formula:

$$PPV_{R0} = K \cdot Q^{\alpha} \cdot r^{-\beta} = K \cdot (R_0)^{\beta} = K \cdot (\frac{Q^n}{r})^{\beta} \tag{3}$$

K, α, β - empirical data related to a given location, geology, and blasting method; r –the distance between the charge and the measuring point; Q – maximum explosive charge per delay; $n = \alpha/\beta$.

In order to determine the proper effectiveness of multi-face destress blasting, it is also necessary to determine the local tendency to strengthen/suppress the seismic wave depending on the increasing amount of explosives S. It can be done by means of the following formula:

$$S = ב \cdot {Q_{total}}^{\epsilon} \tag{4}$$

ב i ϵ – empirical constants describing local geological and mining conditions; Q_{total} – the total amount of fired explosives.

The time component of formula 1 (E_t) makes it possible to determine whether the duration of vibrations induced by multi-face blasting is at the appropriate level in relation to the delay times of the detonators used during the blasting. E_t can be defined by the formula:

$$E_t = \left(\frac{t_{rec}}{t_{max}}\right)^{\theta} \tag{5}$$

t_{rec} – duration of seismic vibrations; t_{max} – detonation time of the last charge (hole) in the group of faces; θ –empirical constant describing the effect of vibration time on the level of the seismic effect.

The last component used in the calculations of the B_{ef} factor describes the effect of the dominant frequency of seismic vibrations on the level of seismic energy generated at the measurement site. A decrease in the frequency of vibrations causes a rise in the observed displacements, which theoretically increases the probability of disintegration of the medium. From the point of view of rock burst prevention, the optimal frequency of the induced seismic wave should be close to the natural frequency of the rock mass. Therefore, the frequency component of the seismic effect (E_f) can be described by the formula:

$$E_f = \left(\frac{1}{\sqrt{(f_n - f_d)^2 + 1}}\right)^{\vartheta} + 1 \qquad (6)$$

f_n – natural frequency of the rock mass; f_d – dominant frequency of seismic waves; ϑ – empirical constant describing the effect of the frequency component on the seismic effect.

The empirical constants (θ) and (ϑ) used in formula 5 and 6 can be determined based on an analysis of the signal's energy distribution using time-frequency decomposition methods, e.g. STFT. According to the analysis carried out for the examined mining panel, the constant (θ) describing the weight of the time component (E_t) in this particular area reaches the value of 0.45, while the empirical constant (ϑ) describing the weight of the frequency component (E_f) takes the value of 1.85. Having a sufficient population of results both constants were determined based on statistical design of experiments (DOE) and regression methods. In turn, the approximate value of the natural frequency of the rock mass (f_n) was determined on the basis of seismic recordings performed within the analysed mining panel. Preliminary analyses show that the eigenfrequency of vibrations in the rock mass in the analysed area is about 3.5 Hz.

3 RESULTS AND DISCUSSION

3.1 Determination of individual components of the B_{ef} factor

Based on the data collected in terms of seismic records after blasting and information on the number of faces, the amount of explosives, and the spatial location of faces, the PPV_{R0} index was calculated, which is a representation of the peak value of vibrations generated by the detonation of explosives in the cut holes. The procedure for determining the PPV_{R0} model has been described in section 2.3. The developed model represents the minimum seismic efficiency of blasting works, assuming a complete lack of amplification of propagating waves from individual faces. A summary of the estimated values of PPV_{R0} in relation to the values recorded in-situ are shown in Figure 2.

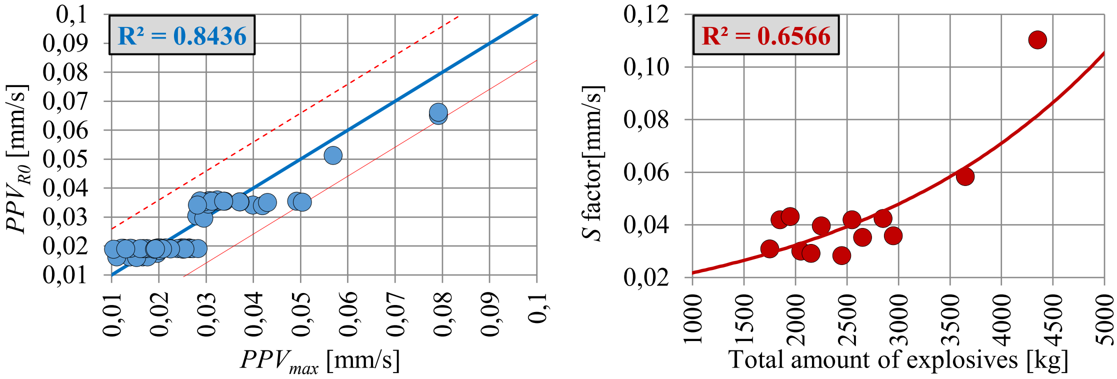

Figure 2. Comparison of measured and estimated values of PPV_{R0} for seismic site no. 30 (left) and characteristic of seismic amplification factor S distribution in relation to the amount of explosives (right).

Based on collected data, empirical factors used in formula 3 and 4 were determined. Values of n, K, and β factors are presented in Table 1.

Table 1. The values of the determined empirical parameters used to develop the predictive model.

Empirical parameters for PPV_{R0} (formula 3)			Empirical parameters for S (formula 4)	
n	K	β	ב	ϵ
0.66	1.3476	0.8497	0.01469369	0.0003939

The distribution of the E_f and E_t component for analysed mining panel are presented in Figure 3.

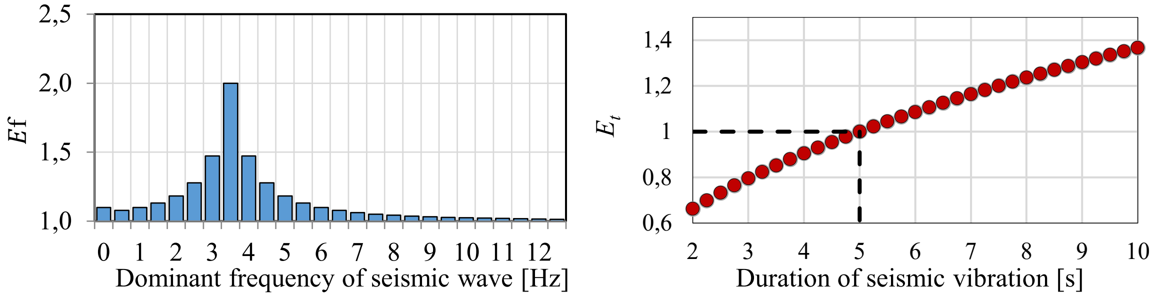

Figure 3. Variability of the E_f component of the formula 1 for rock mass with natural frequency of 3.5 Hz (left) and the distribution of the E_t (formula 1) for blasting in which the maximum delay of the detonators is 5,000 ms (right).

3.2 *Determination of destress blasting effectiveness in the analysed area*

After taking into account all the components describing the seismic effect of particular multi-face blasting, the E_{sa} and B_{ef} factors were determined for 61 cases (Figure 4).

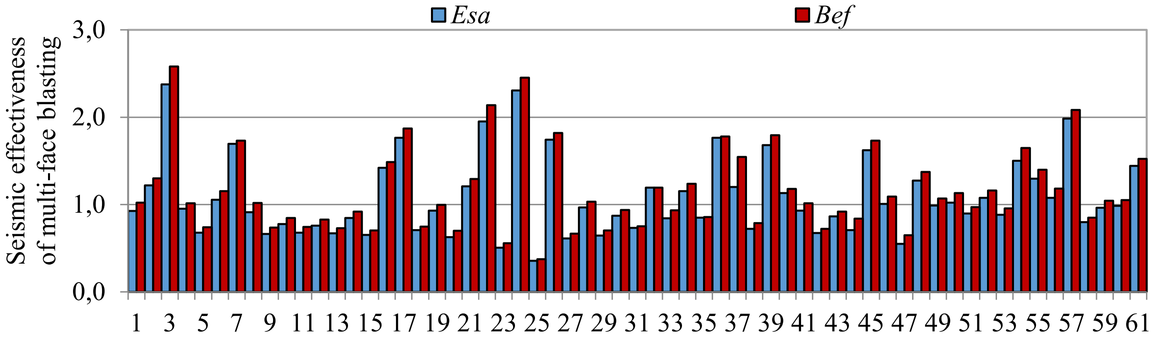

Figure 4. Distribution of E_{sa} and B_{ef} factors for all 61 analysed cases.

Interpretations of E_{SA} and B_{EF} factors are described in Table 2.

Table 2. Interpretation of E_{SA} and B_{EF}.

E_{SA}		B_{EF}	
E_{SA}< 0.9	Blasting ineffective	B_{EF}< 1.0	Blasting ineffective
E_{SA}< 0.9-1.1	Blasting moderately effective	B_{EF}=1.0-1.2	Blasting moderately effective
E_{SA}<1.1	Blasting effective	B_{EF}> 1.2	Blasting effective

According to performed analysis, only 1/3 of blasting operations in the analysed area generated seismic effect which can be considered satisfactory. In 2/3 of cases there was no visible amplification of seismic waves or wave propagation from subsequent faces tends to be damped as a result of negative wave interference. One may conclude that, comparing the E_{SA} and B_{EF} factors make it possible to verify the effect of vibration duration and dominant frequency on the overall seismic effect of multi-face blasting. According to the results of the calculation, in most cases, both parameters do not significantly affect the distribution of the seismic signal energy, but it has to be highlighted that in the analysed cases it resulted mainly from the large differences between the natural frequency of the rock mass and the dominant frequency of vibrations induced by blasting works. Such information can be used already at the stage of designing of drilling and blasting patterns, as the modification of the delay times used in individual faces and may contribute to reducing the dominant frequency of vibrations induced by blasting. The closer this frequency is to the natural vibration frequency of the rocks, the greater the probability that the rock mass will be introduced into resonance which causes its weakening and, as a result, rock mass destressing may be observed.

4 CONCLUSION

This article presents the results of the analysis of the effectiveness of multi-face destress blasting in a selected panel of a Polish copper mine using a novel method based on the analysis of the characteristics of induced seismic waves in terms of the distribution of amplitude, frequency and time in relation to the parameters of individual blasting operations. The empirical constants used at the stage of calculating the vibration prediction models were estimated on the basis of 60 records from multi-face blasting characterised by a different number of faces, different amounts of the explosive, spatial distribution of face locations, and applied delays of detonators. Then, based on the dependencies of actual seismic records and taking into account the seismic effect that should be observed for individual cases, the effectiveness of multi-face blasting, with the use of E_{SA} and B_{EF} factors was evaluated for a group of another 60 events. As a result of the analysis, it was found that only 31% of the blasting can be considered as effective with respect to generated seismic effect. The remaining 69% of events include 25% of moderately effective cases, i.e. those in which the amplitude level is equal to the PPV generated by the detonation of a single face, and 44 of ineffective cases, i.e. those in which the detonation of individual faces in a group led to mutual suppression of the seismic wave, and as a result, the effect was worse than when detonating a single mining face. The knowledge of the effectiveness of the conducted works will be the basis for undertaking corrective actions aimed at increasing the level of amplitude generated by blasting, which will also increase the effectiveness of rock mas destressing. Further work will be focused on modifications of the applied drilling and blasting patterns and the selection of an appropriate firing sequence in order to amplify the vibrations induced by the detonation of subsequent mining faces.

REFERENCES

Vennes, I. & Mitri, H. 2017. Geomechanical effects of stress shadow created by large-scale destress blasting. Journal of Rock Mechanics and Geotechnical Engineering, 9(6), pp. 1085–1093.

Fuławka, K., Mertuszka, P., Pytel, W., Szumny, M. & Jones, T. 2022. Seismic evaluation of the destress blasting efficiency. Journal of Rock Mechanics and Geotechnical Engineering, S1674775522000130. DOI: 10.1016/j.jrmge.2021.12.010

Kan, J., Dou, L., Li, J., Li, X., Bai, J., & Wang, M. 2022. Characteristics of Microseismic Waveforms Induced by Underground Destress Blasting: Comparison With Those Induced by Ground Blasting and Coal Mining. Frontiers in Earth Science, 10, 797358. DOI: 10.3389/feart.2022.797358

Caputa, A. & Rudziński, Ł. 2019. Source Analysis of Post-Blasting Events Recorded in Deep Copper Mine, Poland. Pure and Applied Geophysics, 176(8), pp. 3451–3466. DOI: 10.1007/s00024-019-02171-x

Li N., Li B., Chen D., Wang E., Tan Y., Qian J., Jia H., 2020. Waveform characteristics of earthquakes induced by hydraulic fracturing and mining activities: comparison with those of natural earthquakes. Natural Resources Research, vol. 29, pp. 3653–3674.

Konicek, P., Saharan, M. R., & Mitri, H. 2011. Destress Blasting in Coal Mining – State-of-the-Art Review. Procedia Engineering, 26, pp. 179–194. DOI: 10.1016/j.proeng.2011.11.2157

Mutke, G. 2016. Peak particle velocity as an indicator of dynamic load exerted on the support of underground workings. Acta Geodynamica et Geomaterialia, pp. 367–378. DOI: 10.13168/AGG.2016.0019

Nicholls H.R., Johnson C.F., Duvall W.I., 1971. Blasting vibrations and their effects on structures. Bulletin 656, US Department of Interior, Bureau of Mines, Pittsburgh.