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# Analysis of stress level during longwall mining of a coal seam with the use of seismic effect method

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Abstract. The paper presents an estimation of the effectiveness of long-hole destress blasting during longwall mining of the upper layer of coal seam No. 504 in one of the hard coal mines in the Polish part of the Upper Silesian Coal Basin. The estimation was based on the seismic effect method. The exploitation in concern proceeded under variable geological and mining conditions, mostly in the rock mass destressed by an earlier exploitation of the coal seam No. 506 (approx. 15-38 m below), under the influence of the edges of coal seams No. 418 and 502 (approximately 99-104 m and 30-52 m above) and near the diagonal fault with a throw of 110 m. The results have been compared with the seismic effects of the long-hole destress blasting executed during earlier longwall mining of the coal seam No. 506 in this area. The influence of extraction of the coal seam No. 506 on the stress level reduction was estimated according to the seismic effect method. Similarly, the manner in which the edges in coal seams No. 502 and 418 had an impact - despite the rock mass relaxation effect - on the stress level increase during longwall mining of the upper layer of coal seam No. 504, has been determined.

#### 1. Introduction

Induced seismicity has been observed in the Upper Silesian Coal Basin (USCB) since the 19<sup>th</sup> century. Disturbing the original state of equilibrium that is natural for the rock mass, it has been the main reason for the occurrence of tremors. Seismic and rockburst hazards are closely related. A rockburst can be defined as a dynamic event caused by a tremor, resulting in a sudden destruction or damage of a working or its part. As a result of a rockburst, a working may lose its functionality. This phenomenon is a menace to miners in underground workings.

Seismic and rockburst hazards currently and commonly occur during underground mining of coal seams in the Upper Silesian Coal Basin, both in the Polish and Czech parts. These hazards constantly accompany the exploitation, and their minimization is significant to the safety of crews working in underground excavations. Extraction of coal seams is performed under increasingly complicated geological and mining conditions due to the stress levels in the rock mass, caused by e.g. the increasing depth of exploitation, dislocations (folds, faults), seam edges and remnants of earlier exploitation. The stress concentration in the rock mass should be effectively eliminated.

If it is possible, the exploitation is designed within the area destressed by an earlier extraction of the surrounding coal seam and is planned after a short period following the previous exploitation. Even then, however, stress concentration in the rock mass may not be excluded, especially near the

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edges or remnants of other seams. This stress concentration may be actively eliminated, e.g. by long-hole destress blasting, mainly in the roof rocks of the coal seam.

To determine the effectiveness of long-hole destress blasting, the seismic effect method can be applied. This method, used previously in the Czech Republic [1-12], was applied in previous [13-15] and present studies to analyze the conditions occurring in a Polish hard coal mine in the Upper Silesian Coal Basin. In the seismic effect method, the energy of a provoked tremor and the weight of the used explosives are considered. The effectiveness of long-hole destress blasting may provide information about stress levels in the rock mass. If – despite the large weight of explosives – the effect is insignificant, it may indicate the absence of stress concentrations. Sometimes, however, even a small weight of explosives may cause a medium-  $(10^4 \text{ J})$  or high-energy tremor ( $\geq 10^5 \text{ J}$ ) [13-15]. If the energy of the provoked tremor is higher than it would be expected based on the weight of the detonated explosives, it testifies of the release of energy accumulated in the rock mass and the elimination of stress concentration.

The seismic effect method was applied to determine the effectiveness of long-hole destress blasting executed during longwall mining of the upper layer of a thick coal seam No. 504, under variable geological and mining conditions. The effectiveness has been estimated for blasting performed in the rock mass destressed by an earlier extraction of the coal seam No. 506, or near the seam edges, where the stress increase was expected. The results were compared with each other and with the effectiveness of the long-hole destress blasting executed during the earlier exploitation of the coal seam No. 506 in this area, before stress relaxation.

# 2. Geological and mining conditions

The selected longwall was designed in the upper layer of the coal seam No. 504 deposited at a depth between 997-1034 m below the surface. The thickness of the coal seam No. 504 varies from about 4.3 m to 6.4 m, and increases in the Western direction. The longwall cross-cut was located in the eastern part, close to the downthrown side of the fault with the throw of h = 50 m. The longwall face subsequently proceeded from the east to the west, along the upthrown side of the diagonal fault (throw h = 110 m). The run of the longwall face ended near the border of the protecting pillar for drifts located in the western part. The dip of the coal seam No. 504 ranges from 2° to 14°, mostly in the western and south-western directions.

The longwall mining process was performed with caving, mostly under the extraction level. The depth of exploitation resulted in high levels of stress, theoretically reaching approx. 26 MPa.

The coal seam No. 504 has a tendency to burst (uniaxial comprehensive strength  $R_c$  of approx. 20 MPa). However, the extraction of the coal seam No. 506, deposited 15-38 m below the coal seam No. 504, performed approximately 6 years earlier, had destressed the rock mass in the area of the selected longwall to a certain degree.

The direct roof of the coal seam No. 504 consists of alternating layers of shale, sandy shale and sandstone (figure 1). Three layers of sandstones (11-, 26- and 22-meters thick) are deposited above the coal seam No. 504, 17 m, 38 m and 82 m above, respectively. The breaking of these layers of sandstones could be potentially responsible for the occurrence of high-energy tremors. In the floor of the coal seam No. 504, shale is the dominant rock (figure 1). According to the nearest borehole, the coal seam No. 506 is deposited approximately 17 m below the floor of coal seam No. 504.



Figure 1. Lithological structure of rock mass in the area of selected longwall.

#### 3. Seismic monitoring of the selected longwall

The seismic network consisted of 15 seismic stations, located in underground workings at a depth of 160-1000 m. The network comprised of vertical-component sensors including both SPI-70 seismometers and DLM-2001 geophones. The P-wave first arrival method was used to obtain the locations of seismic events. The error of epicentral location in the area of the selected longwall was in the range of approx. 35-80 m, while the error of vertical coordinate Z was between about 50 m and 100 m (assuming the P-wave first arrival time error of 10 ms and the velocity model error of 20 m/s). Generally, the error of source location increased to the east, because of the configuration of seismic stations, which were located mostly to the west and north-west. With the use of this seismic network, a dataset to study the site was obtained.

The seismic energy  $E_{ICM}$  of tremors was calculated using the numerical integration method. The square of the amplitude  $A_i$  in the *n* following samples (between start and end markers), the sampling rate *f* (200 Hz), the density of rock mass  $\rho$  (2600 kg/m<sup>3</sup>), the attenuation of rock mass – quality factor (30), which reciprocal is present in factor *b*, the calibration factor  $k_i$ , the distance between the focus and the seismic station  $r_i$  (also incorporated in the depth factor  $d_i$ ), the seismic wave velocity  $v_i$  (mostly of about 3800-4100 m/s) were the parameters for the calculation of energy in each of the seismic stations. Calculations were made according to the formula given by [18], which in a simplified form is presented below:

$$E_{ICM} = 2 \cdot \pi \cdot r_i^2 \cdot \rho \cdot v_i \cdot \frac{1}{k_i^2} \cdot f \cdot e^b \cdot d_i \cdot \sum_n A_{i,n}^2$$
(1)

The energies of all seismic stations were arithmetically averaged providing the seismic energy  $E_{ICM}$  of each tremor. The seismic energy of the provoked tremors was calculated in an analogous manner.

The complicated geological and mining conditions referred to above were reflected in the observed seismic activity. The total number of seismic events induced by mining reached 2573, with a total released tremor energy of  $5.2 \cdot 10^8$  J, including 2180 tremors with the energy of  $10^2$  J ( $0.11 \le M_L < 0.63$ ), 324 tremors with the energy of  $10^3$  J ( $0.63 \le M_L < 1.16$ ); 63 tremors with the energy of  $10^4$  J ( $1.16 \le M_L < 1.68$ ), 4 tremors with the energy of  $10^5$  J ( $1.68 \le M_L < 2.21$ ), 1 tremor with the energy of  $9 \cdot 10^6$  J ( $M_L = 2.71$ ), and 1 tremor with the energy of  $5 \cdot 10^8$  J ( $M_L = 3.63$ ). The values of the local magnitude in brackets have been calculated according to the formula given by [16].

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The strongest tremors with the energy of  $9 \cdot 10^6$  J ( $M_L = 2.71$ ) and  $5 \cdot 10^8$  J ( $M_L = 3.63$ ) were associated with the edge of coal seam No. 418 and the diagonal fault, respectively (figure 2).

Other high-energy tremors, with the energy of  $10^5$  J ( $1.68 \le M_L < 2.21$ ) were mostly due to the fracturing of thick layers of sandstones, deposited in the roof of the coal seam No. 504, in the direct vicinity of edges of coal seams No. 418 and 502. One tremor with the energy of  $10^5$  J occurred near the edge of coal seam No. 506.

Because of the complicated geological and mining conditions, affecting the level of seismic activity and rockburst hazard, appropriate active rockburst prevention had to be applied.



Figure 2. Location of tremor sources induced during mining of the coal seam No. 504 with the longwall in concern.

# 4. Active rockburst prevention for the selected longwall

The exploitation of the upper layer of the coal seam No. 504 was designed in the area mostly destressed by the earlier exploitation of the coal seam No. 506 (15-38 m below the former). The seam No. 504 is, however, located in the vicinity of the edges of coal seams No. 418, 502 and 506. In these conditions, the main form of active rockburst prevention that was applied was long-hole destress blasting in the roof rocks. In each case immediate tremors were provoked, in some instances, however, aftershocks occurred.

Blastholes were drilled from the longwall face and from the maingate and tailgate sides (figure 3). The diameter of each blasthole was 76 mm. A special methane explosive – Emulinit PM – was used. The explosion heat of this explosive material was 2278 kJ/kg, and the minimum velocity of detonation was 4000 m/s [17]. Immediate methane electric detonators were used to initiate the explosives. All blastholes within one blast were detonated in the same moment, without delay.

When the longwall was in the start-up phase, after about 15 meters of the longwall face advance, the first blast from the longwall face was executed to facilitate the first goaf formation. Blastholes were arranged in pairs, drilled at a distance of ca. 90 m from the maingate and tailgate. In each pair, the blastholes were drilled from the longwall face to the north-eastern and south-eastern directions at an angle of ca. 70°. The length of each blasthole was 35 m. Blastholes were inclined upwards at an angle of 50° relative to the horizon. During the first blast, 192 kg of explosives were detonated (48 kg per blasthole), which provoked a tremor with the seismic energy of  $6 \cdot 10^3$  J ( $M_L = 1.04$ ).

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The subsequent seven blasts were executed to reduce the possible stress concentrations in roof rocks ahead of the longwall face, in the vicinity of the edges of the coal seams No. 418 and 502. Blastholes were drilled to the western direction, perpendicularly to the longwall face (figure 3). Two blastholes were drilled at a distance of about 70 m from the maingate and tailgate, and one in the middle of the longwall face. The blastholes referred to above were 50 m long, and their inclination was 50° in relation to the horizon and thus the explosive material was located in the first, 11 meters thick layer of sandstone above the coal seam No. 504 (figure 1). In total, 288 kg of Emulinit PM was detonated during each blast (96 kg per blasthole). Tremors with the seismic energy of  $1 \cdot 10^4$  J ( $M_L = 1.16$ ),  $8 \cdot 10^3$  J ( $M_L = 1.11$ ),  $8 \cdot 10^3$  J ( $M_L = 1.11$ ),  $3 \cdot 10^4$  J ( $M_L = 1.41$ ),  $2 \cdot 10^4$  J ( $M_L = 1.32$ ),  $5 \cdot 10^4$  J ( $M_L = 1.53$ ), and  $4 \cdot 10^4$  J ( $M_L = 1.47$ ) were provoked, respectively. After the last long-hole destress blasting from the longwall face, an aftershock occurred with the seismic energy of  $2 \cdot 10^4$  J ( $M_L = 1.32$ ).

Destress blasts were also executed from the maingate and tailgate sides (figure 3). These blasts were executed mainly to reduce the potential stress concentrations near the edges of the coal seams No. 418, 502 and 506, and to create a fracture zone, where the dissipation of the energy of strong tremors would take place. Blastholes were drilled every 40 m. These blastholes were deviated alternating to the south-west and north-west from the main and tailgates at an angle of 40°. These blastholes were inclined upwards at the angle of  $50^{\circ}$  relative to the horizon, and were 35 m long. 48 kg of Emulinit PM was loaded into each blasthole. Blasts from the maingate and tailgate sides were mostly performed using 3 blastholes, but detonation of explosives in 2 and 4 blastholes was applied as well. In total, 8 blasts (with the use of 23 blastholes) were executed from the maingate side (No.1-7 and 10). The blasts from the maingate side mentioned above, provoked tremors with the seismic energies of:  $4 \cdot 10^3$  J ( $M_L = 0.95$ ),  $5 \cdot 10^3$  J ( $M_L = 1$ ),  $5 \cdot 10^3$  J ( $M_L = 1$ ),  $1 \cdot 10^4$  J ( $M_L = 1.16$ ),  $8 \cdot 10^3$  J  $(M_L = 1.11)$ , 2.10<sup>4</sup> J ( $M_L = 1.32$ ), 2.10<sup>4</sup> J ( $M_L = 1.32$ ) and 3.10<sup>3</sup> J ( $M_L = 0.88$ ) (beginning from the blasting closest to the longwall cross-cut). After the weakest tremor produced by the last blasting (with modified deviation of blastholes), an aftershock with the energy of  $2 \cdot 10^3$  J ( $M_L = 0.79$ ) occurred. In total, 7 blasts (with the use of 21 blastholes) were executed from the tailgate side (No. 1-7). These blasts provoked tremors with the seismic energies of:  $3 \cdot 10^4$  J ( $M_L = 1.41$ ),  $2 \cdot 10^3$  J ( $M_L = 0.79$ ),  $5 \cdot 10^3$  J  $(M_L = 1)$ ,  $1 \cdot 10^4$  J  $(M_L = 1.16)$ ,  $4 \cdot 10^3$  J  $(M_L = 0.95)$ ,  $5 \cdot 10^3$  J  $(M_L = 1)$ , and  $4 \cdot 10^3$  J  $(M_L = 0.95)$  (order as previously).

From the maingate side, in the vicinity of co-occurring edges of the coal seams No. 418, 502 and 506, an additional long-hole destress blasting had been planned. A total of 3 blastholes were drilled, perpendicularly to the southern direction (figure 3). These blastholes were ca. 100 m long, and their inclination was  $60^{\circ}-65^{\circ}$  in relation to the horizon. Every blasthole was loaded with 144 kg of explosives, so the column was located in the thickest (26 meters) layer of sandstone (figure 1). The detonation of explosives in one blasthole (blast No. 8) provoked a tremor with the energy of  $2 \cdot 10^4$  J ( $M_L = 1.32$ ), while the detonation of 288 kg of explosives in two blastholes (blast No. 9), and closer to edges of the seams referred to above, produced a tremor with the seismic energy of  $5 \cdot 10^4$  J ( $M_L = 1.53$ ).



**Figure 3.** Locations of blastholes and sources of provoked tremors during the mining of the coal seam No. 504 by means of the longwall in concern.

Additional long-hole destress blasting was also executed from the tailgate side, firstly near the edge of the seam No. 418 (blast No. 8) and secondly near the edge of the seam No. 506 (blasts No. 9 and 10). In the vicinity of the edge of the seam No. 418, two blastholes were drilled (figure 3) – one perpendicularly to the northern direction, and one deviated from the tailgate to the north-west at an angle of 70°. These blastholes were inclined at an angle of 60°-65° in relation to the horizon, and were ca. 100 m long. The detonation of 288 kg of explosives (144 kg per blasthole) immediately produced a tremor with the seismic energy of  $1 \cdot 10^4$  J ( $M_L = 1.16$ ). Near the edge of coal seam No. 506, a total of 4 blastholes were drilled perpendicularly to the northern direction. Their length and inclination to the horizon was similar as in the case of the blasting performed near the edge of the coal seam No. 418. A total of 288 kg of explosives was detonated in two blastholes closer to the longwall face and to the edge of seam the No. 506 (144 kg per blasthole), which provoked a tremor with the energy of  $3 \cdot 10^4$  J( $M_L = 1.41$ ). The detonation of 288 kg of explosives in the other two blastholes (144 kg per blasthole) produced a tremor with the seismic energy of  $1 \cdot 10^4$  J ( $M_L = 1.10^4$ ).

After the strongest tremor with the energy of  $5 \cdot 10^8$  J ( $M_L = 3.63$ ), a control long-hole destress blasting was executed to eliminate the stress concentration to the south from the tailgate, near the diagonal fault (blast No. 11). In two blastholes, drilled perpendicularly to the South, ca. 35 m long, and inclined upwards at the angle of 50° to the horizon, a total of 96 kg of explosives (48 kg per blasthole) was detonated. This blasting provoked an immediate tremor with the seismic energy of  $5 \cdot 10^3$  J ( $M_L = 1$ ).

The effectiveness of the long-hole destress blasting from the longwall face and the sides of the gates of the selected longwall in the coal seam No. 504 has been calculated via the seismic effect method.

# 5. The seismic effect method

The effectiveness of the long-hole destress blasting depends on the level of the stress release in the rock mass. This stress release may be evaluated by means of the seismic effect (*SE*). This methodology was established in the Czech part of the USCB by [1], subsequently verified by [2-12],

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and adjusted to the conditions occurring in the Polish part of the USCB, in the colliery in concern [13-15].

The seismic effect (SE) is defined as the ratio of seismic energy released in the rock mass upon blasting, to the energy of a given detonated charge [7]. The seismic effect (SE) can be calculated as follows:

$$SE = \frac{E_{ICM}}{K_{ICM}Q}$$
(2)

where  $E_{ICM}$  denotes the seismic energy in [J] calculated by the seismic network in the investigated coal mine with the use of the numerical integration method, Q is the weight of the explosive charge in [kg] and  $K_{ICM}$  is the coefficient characterizing the conditions in the considered mine [J/kg]. The  $K_{ICM}$  coefficient referred to above must be determined for the conditions in which the seismic monitoring is carried out, while the seismic energy of the registered seismic events is calculated in the same manner [7]. The  $K_{ICM}$  coefficient determined for the selected hard coal mine in the Polish part of the USCB amounts to  $K_{ICM} = 59.23$  J/kg [13].

The obtained value of the  $K_{ICM}$  coefficient was used to establish the classification system for the evaluation of *SE* [13]. This classification was made according to the distribution of the data probability from the calculated seismic effects. The first quintile, median, the third quintile and the maximum values were determined using the entire data set of the seismic effect (1.4; 2.3; 3.5; 5.9, respectively) [13]. The outliers were also determined. Based on the mentioned statistical parameters, the degrees of stress release due to destress blasting were determined [13]. If the seismic effect *SE* was lower than the first quintile, the effect of blasting was considered insignificant (the registered energy released by blasting was less than 1.4 times the explosion energy) [13]. A seismic effect higher than the maximum (outliers) was considered excellent (the registered energy released by blasting was higher than 5.9 times the explosion energy) [13]. The classification system developed to evaluate the *SE* values based on the criteria obtained from data distribution probabilities has been presented in table 1.

Although seismic energy is fundamental to the stress release effect and the *SE* calculations, it represents only a small portion of the total blasting energy, with a considerable amount of the seismic energy observed in rock mass stress release [7, 13]. It should be noted that the evaluation of destress blasting effectiveness according to *SE* calculation alone represents an evaluation of only the main goal of destress blasting, that goal being the stress release [7, 13].

The seismic effect (SE)	The evaluation of seismic effect	Percentage of data set
SE < 1.4	insignificant	20.7
$1.4 \le SE < 2.3$	good	29.1
$2.3 \le SE < 3.5$	very good	25.1
$3.5 \le SE < 5.9$	extremely good	19.5
$SE \ge 5.9$	excellent	5.6

Table 1. Classification system for the evaluation of SE in the considered colliery [13].

# 6. Results

During longwall mining of the upper layer of the coal seam No. 504, a total of 29 blasts were executed. The total weight of explosives amounted to 5712 kg. The effectiveness of these blasts has been estimated based on the calculated *SE* values, according to table 1. The evaluation of the seismic effect *SE* of the blasts conducted from the longwall face has been presented in table 2.

No.	No. of blastholes	Q [kg]	$E_{ICM}$ [J]	SE	Evaluation of SE
1	4	192	6E3	0.5	insignificant
2	3	288	1E4	0.6	insignificant
3	3	288	8E3	0.5	insignificant
4	3	288	8E3	0.5	insignificant
5	3	288	3E4	1.8	good
6	3	288	2E4	1.2	insignificant
7	3	288	5E4	2.9	very good
8	3	288	4E4	2.3	very good

Table 2. Parameters of destress blasts in the roof rocks executed from the longwall face.

The effectiveness of blasts conducted from the side of the maingate, estimated based on the calculated *SE* values, has been shown in table 3.

No.	No. of blastholes	Q [kg]	$E_{ICM}$ [J]	SE	Evaluation of SE
1	3	144	4E3	0.5	insignificant
2	4	192	5E3	0.4	insignificant
3	3	144	5E3	0.6	insignificant
4	3	144	1E4	1.2	insignificant
5	3	144	8E3	0.9	insignificant
6	3	144	2E4	2.3	very good
7	2	96	2E4	3.5	extremely good
8	1	144	2E4	2.3	very good
9	2	288	5E4	2.9	very good
10	2	96	3E3	0.5	insignificant

**Table 3.** Parameters of destress blasts in the roof rocks executed from the maingate side.

In table 4, the effectiveness of blasts executed from the tailgate side, estimated according to the calculated *SE* values, has been presented.

No.	No. of blastholes	Q [kg]	$E_{ICM}$ [J]	SE	Evaluation of SE
1	3	144	3E3	0.4	insignificant
2	4	192	2E3	0.2	insignificant
3	3	144	5E3	0.6	insignificant
4	3	144	1E4	1.2	insignificant
5	3	144	4E3	0.5	insignificant
6	3	144	5E3	0.6	insignificant
7	2	96	4E3	0.7	insignificant
8	2	288	1E4	0.6	insignificant
9	2	288	3E4	1.8	good
10	2	288	1E4	0.6	insignificant
11	2	96	5E3	0.9	insignificant

**Table 4.** Parameters of destress blasts in the roof rocks executed from the tailgate side.

# 7. Discussion

From the longwall face a total of 8 blasts were executed. The effectiveness of the first four blasts from the longwall face was particularly low (table 2). This exhibited the effective destress of the rock mass in this area. On the contrary, the effectiveness of the next four blasts, in the vicinity of the edges of

coal seams No. 418 and 502 was higher (good, very good, and in one case insignificant, but close to good). The effects of these blasts confirmed the presence of stress concentration in this area.

Similarly to the first blasts from the longwall face, the effectiveness of the first three blasts from the maingate side was very low (table 3). The rock mass in this area was effectively destressed, and the influence of the single edge of the coal seam No. 502 on the stress level was negligible. The effectiveness of blasting from the maingate side was increasing closer to the co-occurring edges of the coal seams No. 418, 502 and 506, (blasts No. 4 and 5 from the maingate side), remaining, however, insignificant. In the vicinity of the edges of coal seams No. 418, 502 and 506 mentioned above, the effectiveness of the long-hole destress blasting from the maingate side was very good or extremely good. This exhibited the stress concentration in the rock mass in that area. The effect of the final blast from the maingate side (No. 10), in the vicinity of the single edge of the coal seam No. 502 was insignificant, probably due to the large distance from the zone of stress concentration near the edges of the surrounding coexisting coal seams. A single edge of coal seam No. 502 influenced the stress level in the rock mass to a smaller degree.

The effectiveness of the blasts executed from the tailgate side was mostly insignificant (table 4), and the values of *SE* were generally very low. The rock mass had been effective destressed by an earlier extraction of coal seam No. 506 and by the high-energy tremor of  $5 \cdot 10^8$  J ( $M_L = 3.63$ ) on the diagonal fault. The effectiveness of a single blast from the tailgate side (No. 9), near the edge of the coal seam No. 506, was good. It is probable that a local stress concentration was present in this area. The effectiveness of the blast No. 4 from the tailgate side, in the close vicinity of the edge of the coal seam No. 418, was insignificant, but close to good (table 4). In this area, the edge referred to above somewhat influenced the stress level in the rock mass. The influence was, however, slight.

During the mining of the coal seam No. 506, approx. 15-38 m below the longwall panel in the coal seam No. 504, active rockburst prevention was applied [15]. A total of 55 blasts were executed; 5 of them with blastholes drilled from both the longwall face and tailgate side [15]. Because of the large distance between the blastholes and different stress conditions, the effects of these blasts could not be taken into consideration. Among the remaining 50 blasts, 43 were executed from the longwall face and 7 from the maingate side [15]. The column of the explosive material was located in the roof rocks of the coal seam No. 506 [15], which consisted of alternating layers of shale, sandy shale and sandstone (figure 1). The extraction of the coal seam No. 506, which was not previously destressed, required a wider range of active rockburst prevention. A total of 14 424 kg of explosives were detonated in the 50 blasts referred to above. The weight of the explosives used in two blasts amounted to 576 kg, while it did not exceed 288 kg in the remaining blasts. The effectiveness of these blasts – according to the seismic effect method - was classified as insignificant (34%), good (22%), very good (34%) and extremely good (10%). For comparison, the effect of approximately 72.4% of blasts during the longwall mining of the upper layer of the destressed coal seam No. 504 was insignificant, despite the placement of explosives in the layers of competent sandstones. According to the seismic effect method, stress concentration in the area of the executed blasts was not observed. The share of good, very good and extremely good effectiveness amounted to 6.9%, 17.2% and 3.5%, respectively. An increase of blasting effectiveness was clearly noted in the vicinity of the co-existing edges of coal seams No. 418, 502 and 506.

# 8. Conclusions

Long-hole destress blasting in the roof rocks is the main form of active rockburst prevention in the considered hard coal mine in the Polish part of the USCB. The estimation of blasting effectiveness may be performed by means of the seismic effect method. The method was applied for the blasts executed for the longwall mining of the upper layer of the coal seam No. 504, destressed by an earlier exploitation of the coal seam No. 506, approximately 15-38 m below the former.

In light of the results, the effectiveness of blasting was mostly insignificant, which exhibits the absence of additional stress concentrations in the rock mass. Generally, only the explosion resulting from the detonation of explosives occurred, in the most cases reduced by the effect of the rock mass

relaxation. The effect of relaxation in the longwall panel in the upper layer of coal seam No. 504 was confirmed by the seismic surveys and other geophysical observations.

The influence of the presence of the edges of the surrounding coal seams on the stress level in the rock mass was reflected by the mostly highly effective blasting. Despite the relaxation of the rock mass, in the vicinity of these edges, local stress concentrations still occurred. However, in comparison with the results obtained during the longwall mining of the coal seam No. 506, in case of which the rock mass was not destressed, the effectiveness of the blasts executed during the longwall mining of the upper layer of coal seam No. 504 was lower.

The seismic effect method may be additionally applied to estimate the effect of rock mass relaxation resulting from e.g. destress extraction or high-energy tremor occurrence. A control blasting may provide an answer regarding the stress levels in the rock mass.

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