

Destress blasting on the border of safety pillars

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ABSTRACT

Destress blasting used at the border of safety pillars represents a special kind of destress blasting. The main goal of this type of destress blasting is to separate relatively more deformed mining areas from a non-mined safety pillar area such as a shaft pillar or cross-cut pillar, in order to reduce the impact of high stress concentration in areas within the safety pillar. Destress blasting is carried out in rigid, competent rocks adjacent to hardcoal seams 5 m to 6 m thick at depths ranging from 700 m to 1000 m below the surface. Total explosive charge of up to 3450 kg is fired simultaneously in three to seven fan-pattern and line-pattern boreholes drilled from the maingate and the tailgate, when the longwall face approaches to within round 100 m of the safety pillar border. Use of this type of destress blasting from hardcoal longwall mining in the Czech part of the Upper Silesian Coal Basin is described here. Natural and mining conditions are described together with the design parameters of destress blasting, registered seismic activity during longwall mining, and evaluation of the stress relief effect calculated from the monitored seismological data. The present study argues for using this kind of destress blasting as a proactive rockburst prevention method during mining of thick hardcoal seams. Destress blasting can decrease high stress levels and consequently minimize rockburst hazards on the border regions of the safety pillars.

KEYWORDS: Coal mining, rockburst, destress blasting

1. INTRODUCTION

Rockburst is one of the most hazardous problems encountered during underground excavations. This phenomenon always involves a violent energy release with large rock deformation and rock ejection that can cause severe damage to openings, equipment, and mine facilities, potentially also causing fatalities (Linkov 1996; Kaiser and Cai 2012). Rockburst is an inherent problem found in overstressed rocks. The stress redistribution caused by excavations induces high stress concentrations around the openings, especially when the excavation is surrounded by thick layers of hard, competent rocks which are capable of storing high amounts of strain energy. At great depth, the mining-induced stress interacts with the high in situ stress of the rock mass causing unfavourable stress concentrations that can trigger explosive rockbursts.

Destress blasting is a very important proactive measure to reduce rockburst risk in areas which are highly prone to violent rock failure in many mining regions. Destress blasting has been used for almost a century mainly in ore mining, but it also presents a very important destress method in the hardcoal mining industry. It is nowadays used as a standard destress technique in high rockburst risk areas in longwall mining in the sedimentary deposits of the Upper Silesian Coal Basin (UCSB).

Destress blasting performed at the borders of mining safety pillars is a special type of destress

blasting and is referred to as the ‘cutting destress blasting’ method. This method aims to decrease the stress concentrations within the safety pillar area, and to protect the pillar from deforming due to mining activity.



Figure 1: Location of the Upper Silesian Coal Basin.

This paper presents the results of three case studies of cutting destress blasting application at the mining of coal seam No. 504 of the Lazy Colliery, in the Czech part of the UCSB (Figure 1). The methodology of each case is described, as well as the blasting efficiency, which is assessed by the calculated seismic effect.

2. DESTRESS MODEL

Safety pillars are non-mined zones where the rock mass is kept relatively intact in order to protect

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important openings, transportation, and ventilation for areas acting as shafts and main roadways.

Safety pillars usually experience significant stress concentrations due to the stress migration from the surrounding mined out areas (Dvorsky and Konicek, 2005).

Cutting destress blasting is a special destress blasting performed at the borders of the safety pillars. This kind of destress blasting has the main goal of creating a physical separation between the deformed mining areas and the non-deformed safety pillar area in order to decrease the impact of additional stress induced inside the safety pillar area. In this way the high stress concentrations can be reduced in specific rock mass regions on the boundary of mined out areas, and lower the risk of rockburst in intact areas in the rock mass. This separation is achieved by cutting the rock mass to create an artificial discontinuity plane that isolates the safety pillar area and protects it from deforming (Dvorsky and Konicek, 2005). In this way, more uniform load and stress distribution occurs in rock mass.

A cutting destress blasting is typically performed by firing a number of blastholes, all located in the same plane. These blastholes can be drilled either

using a lineal layout (i.e. parallel to each other with fixed spacing between them) or using a fan layout (i.e. all of them drilled from the same location but at different angles) (Figure 2). Blasting parameters, such as blasthole length, orientation, and the explosive charge, vary depending on the specific conditions of each area. Groups of blastholes are generally fired in different stages and no firing time delay between blastholes is used at each stage. Using no delay favours the formation of a single breaking plane between the blastholes, instead of the formation of large fractures in all directions around the blastholes.

The cutting destress blasting projects studied in this paper were carried out at the ending part of five panels of the coal seam No. 504. Blasting works of cases No. 1 and No. 2 (panels 140 914 and 140 704, respectively) were performed to protect the shaft safety pillar located at the center of the colliery. Blasting works of case No. 3 (panels 140 302, 140 304, and 140 306) were performed to 'cut out' the safety pillar of SW cross-cuts area

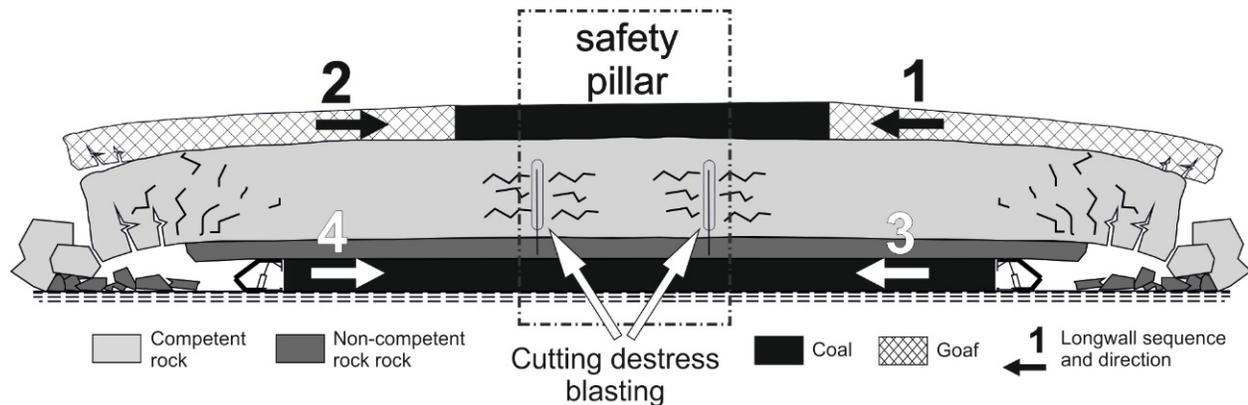


Figure 2: Profile of the cutting destress blasting layout.

3. SITE CONDITIONS

3.1. Geology

The coal seam No 504 is up to 6 m thick and is located up to 800 m below the surface in the lower part of the Sedlove Members (Figure 3). This formation is a sequence of sedimentary rocks that is mainly formed by thick layers of competent sandstones, conglomerates and sandy siltstones. The uniaxial compressive strengths of these sandstones and the conglomerates range between 70 MPa and 120 MPa (Konicek et al., 2013).

Layers of non-competent rocks such as mudstone and siltstone also occur, although they are much thinner and are generally adjacent to coal beds. Coal seams No. 512 and No. 530 have a thickness up to 8 m and are located between 50 m and 80 m above the seam No. 504, depending on the location and about 800 m below surface. The coal of this area has a laboratory compressive strength average of 15 MPa (Konicek et al., 2013).

The Lazy Colliery is highly affected by brittle as well as ductile deformations. The main brittle tectonic elements in this area are large extensional faults with orientation N-S and E-W and amplitudes of tens of meters, and ductile asymmetric anticlinal

structure with N-S direction of fold axis. Main structures establish the limits of different mining blocks in the colliery. Tectonic elements can act as significant stress relief zones, but they also create unregular stress fields in rock mass.

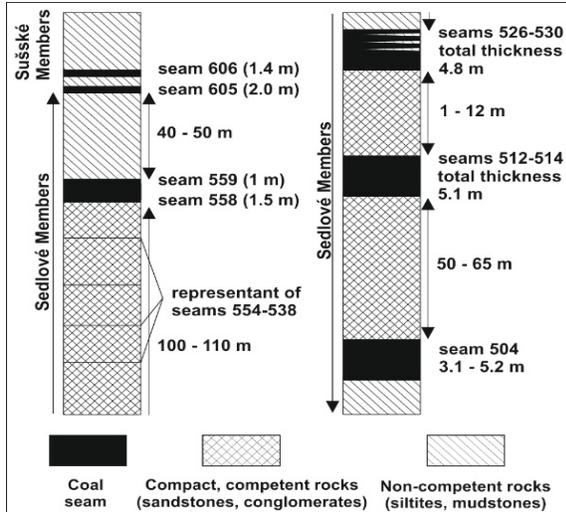


Figure 3: Simplified lithological section of the Sedlove Members in the Lazy Colliery.

3.2. Geomechanics

Mined out panels from upper coal seams No. 512 and 530 and from adjacent areas must be taken into account for the geomechanical analysis of the studied areas. Stress migrates from mined and deformed areas into intact zones of the rock mass that have not been exploited yet. This additional stress in intact rocks produces dangerous stress concentrations that can trigger rockburst during the excavation of new longwalls or galleries. Safety pillars are highly prone to suffer high stress concentrations because of their low deformation level. For that reason, mining works approaching safety pillar borders may significantly increase the risk of rock failure and consequently the rockburst.

Since the energy produced by rock failure rises with the increase of rock strength and brittleness, the occurrence of thick, competent rock strata with high UCS overlaying the seam No. 504 permits the appearance of high stress concentrations that can induce intense rockbursts. Rockburst produced in panels close to safety pillars can seriously worsen the safety and stability not only in the working area, but due to another additional stress, also into the safety pillar itself.

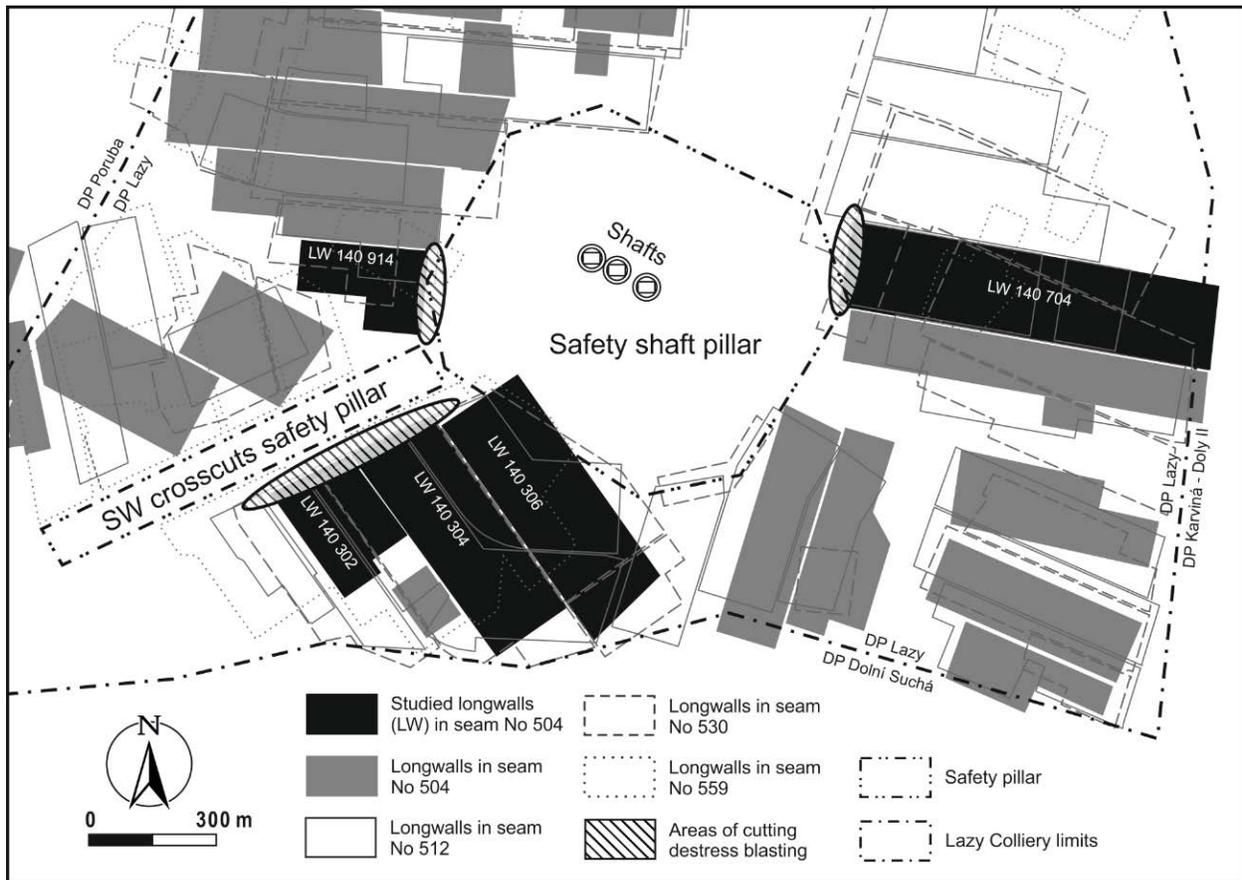


Figure 4: Location of the safety shaft pillar, the SW crosscuts safety pillar and the performed cutting destress blasting.

3.3. Mining

Coal seams of the Lazy Colliery are mined using the longwall caving method. Typical panel sizes are several hundred meters long. The position and orientation of extracted panels in different coal seams are generally not superimposed, due to uneven geological properties and coal pillars left in them (lesser seam thickness, faults etc.) In some cases, coal pillars are left to protect certain zones, such as in the safety pillar areas (Konicek et al., 2013) (Figure 4).

4. CASE NO 1 – LAZY COLLIERY LONGWALL 140 914

Destress blasting works were performed at the longwall 140 914 before and during its excavation. These works included the special cutting destress blasting, which was carried out at the border of the central safety shaft pillar.

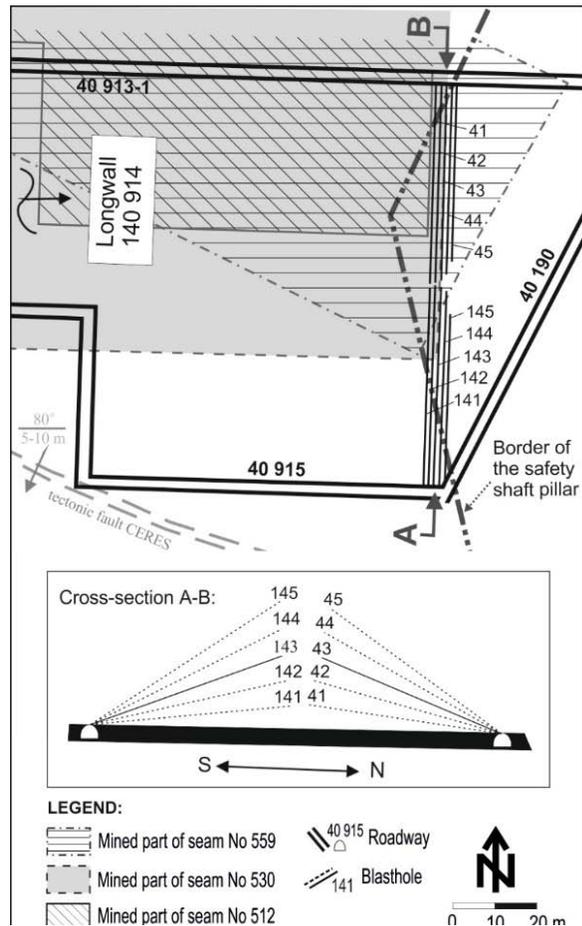


Figure 5: Scheme of the cutting destress blasting carried out in the longwall 140 914 at the border of the safety pillar.

In order to create a physical boundary between the safety pillar and the longwall area, two groups of five blastholes (a total of 10 blastholes) were drilled from the north and south gate-roads into the longwall's overburden. All blastholes were drilled in exactly the same vertical plane, forming two symmetric blasthole fans (Figure 5). The lengths of the blastholes ranged from 93 m to 100 m and their inclination angles varied from 4° to 35° (upwards). They all were drilled with a diameter of 93 mm.

Each group of blastholes was fired separately in two stages, i.e. blastholes No. 41–45 in stage No. 12 and No. 141–145 in stage No. 13 (the stages were numbered for the entire panel mining). Explosives in holes of each stage were fired without a time delay. The explosive charge of each blasthole varied from 595 kg to 780 kg, according to its length and position. The total charge fired in each stage (No. 12 and No. 13) was 3450 kg. The average percentage of the loaded lengths of these blastholes was 74%. All holes were pneumatically charged with gelatine type explosive Perunit 28E and sand was used for the stemming. Blasting parameters are summarized in Table 1.

These two blasting stages were fired when the longwall face was located about 158 m and 152 m from them, respectively. This distance was considered enough to prevent undesirable rock deformations in the safety pillar before it was isolated by the cutting destress blasting.

A continuous seismic monitoring was carried out during mining of the longwall No. 140 914 using local and regional seismic networks and geophones installed in the gate-roads of the panel. The results of seismic monitoring showed that the seismic activity had noticeably grown in the regions loaded by additional stress concentration at the edges of the mined parts of the upper coal seams. The seismic events induced during the longwall mining were mainly located in its overburden, in the area outside from the vertical projection of the upper mined panels of seams Nos. 512 and 530, where the additional stress was concentrated.

From the seismic monitoring it is also clear that the seismic activity rose with the increase of the rate of longwall face advance, the rate of mined coal volume and implementation of destress blasting.

The efficiency of the cutting destress blasting was evaluated by the seismic effect (SE), which is calculated by the equation

$$SE = \frac{E_{OKC}}{K_{OKC}Q}$$

where E_{OKC} is the seismic energy calculated from seismic monitoring in the Ostrava-Karvina Coalfield (OKC), K_{OKC} is a combined coefficient characterized

by natural and mining conditions in OKC (i.e. $K_{OKC} = 2.1$), and Q is the explosive charge (Konicek et al 2013).

In this case, the calculated SE in both blasting stages was 33.1 and 54.2 respectively. This means that the energy released by each blasting was 33.1 and 54.2 times larger than the energy from the explosive. The excess of energy measured in both stages corresponds to the release of the strain energy accumulated in the rock mass.

Hence, it can be stated that the cutting destress blasting carried out in this case had a very high destress effect. The calculated SE can be also evaluated by a qualitative classification according to the criteria shown in Table 2 (Konicek et al 2013). Thus, the efficiency of these cutting destress blasting was 'excellent'. It is seen from the high SE values that the stress concentration at the border of the safety shaft pillar was significantly high and it could have induced rockburst phenomena if the destress blasting had not been applied.

Table 1: Destress rock blasting parameters conducted in longwall 140 914.

Stage	Blasthole number (-)	Explosive charge (kg)	Released seismic energy (J)	SE (-)	SE evaluation (-)
12	41-45	3450	2.40E+05	33.1	Excellent
13	141-145	3450	3.80E+05	54.2	Excellent

Table 2: Classification for evaluation of the seismic effect (Konicek et al 2013).

Seismic effect	Evaluation of seismic effect (SE)
$SE < 1.7$	Insignificant
$1.7 \leq SE < 3$	Good
$3 \leq SE < 6$	Very good
$6 \leq SE < 12$	Extremely good
$SE \geq 12$	Excellent

5. CASE NO. 2 – LAZY COLLIERY LONGWALL 140 704

The area of the longwall 140 704 was significantly influenced by additional stress induced from mined panels in the upper coal seams Nos. 512 and 530, and from mined panels from the same seam located next to it, to the south and to the east. The occurrence of competent rock strata overlaying the seam No. 504 led to critical stress concentrations that induced two intense rockbursts that occurred soon after the start of mining in this longwall. The virgin stress state (vertical components varied between 12 MPa and 21MPa) and induced stress have been determined there. Induced stresses reached up to five multiples of the original stress state (Ptacek et al., 2015). Due to the high rockburst risk of this area, rock failure prevention measures were implemented as soon as the mining of this panel started, including destress blasting. Destress blasting carried out in the longwall 140 704 were very similar than those presented in the case No. 1. In this case, the longwall

also finished at the border of the safety shaft pillar and, in consequence, special destress blasting had to be applied to isolate and protect the safety pillar area from the mining activity.

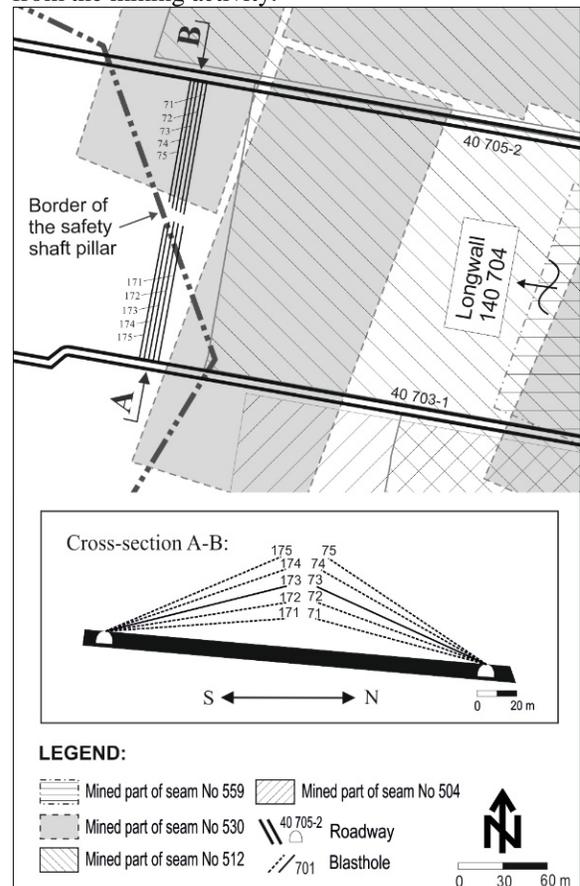


Figure 6: Scheme of the cutting destress blasting carried out in the longwall 140 704 at the border of the safety shaft pillar.

Again, two groups of five blastholes (a total number of 10 blastholes) were drilled upwards into the overburden strata; one group from the northeastern gate-road (blastholes Nos. 71–75) and the other from the southwestern gate-road (blastholes Nos. 171–175). Each group was drilled with a fan layout and all blastholes from both groups were located in the same vertical plane (Figure 6). The 95 mm diameter blastholes were drilled with inclination angles between 4° and 34°. The length of the blastholes ranged from 93 m to 100 m. All blastholes were fired in two stages (i.e. one group per stage), and the explosive in both stages were fired without time delay.

The explosive charge of each blasthole varied depending on its length and position, ranging from 415 kg to 700 kg. The total amount of explosive fired in each stage was 2900 kg in first stage and 2975 kg in second stage. The average percentage of the gelatine loaded lengths of these blastholes was 68%. All blastholes were charged pneumatically with a

gelatine type of explosive and sand was used for the stemming. Blasting parameters are summarized in Table 3. Both stages were fired when the longwall face was located about 168 m and 132 m from the holes, respectively. This distance was considered enough to prevent undesirable rock deformations in the safety pillar before it was isolated by the cutting destress blasting.

Local and regional seismic networks were used to register the seismicity induced by destress blasting. The calculated SE (see in previous section) of these cutting destress blasting was 24.6 for the first stage and 44.8 for the second stage. According to the evaluation criteria shown in Table 2, destress efficiency of these blasting works was considered 'excellent'. These results show a very high stress release at the border of the safety shaft pillar, which suggests that an important improvement of the safety conditions in both the longwall and the safety pillar area was achieved by using destress blasting (Ptacek et al. 2015).

Table 3: Destress rock blasting parameters conducted in longwall 140 704.

Stage	Blasthole number (-)	Explosive charge (kg)	Released seismic energy (J)	SE (-)	SE evaluation (-)
19	71-75	2900	1.50E+05	24.6	Excellent
20	171-175	2975	2.80E+05	44.8	Excellent

6. CASE NO 3 – LAZY COLLIERY LONGWALLS 140 302, 140 304 AND 140 306

A safety pillar had been left in the third mining block of the Lazy Colliery in order to protect the galleries of the SW cross-cuts (SWC). This intact rock area starts from the coal seam No 606+605 at the depth 240 m below surface and continues downwards vertically to the level of the coal seam No. 504 (at up to 670 m below the surface). The safety pillar area is about 900 m long and 200 m wide and has NNE-SSW direction. Mining activity around the SWC safety pillar in the seam No. 504 could produce undesirable rock deformations in the protected area. Moreover, additional stress from adjacent mined panels in seam No. 504 and from mined panels in upper seams Nos. 512 and 530 could also produce dangerous stress concentration in the intact rock of the safety pillar, what might induce intense rockbursts.

For that reason, a large cutting destress blasting was performed to protect the safety SWC pillar from rock deformation and dangerous rock failure. Destress blasting works were designed to isolate the intact rock mass of the SWC safety pillar from the goaf over longwalls 140 302, 140 304 and 140 306,

which were located next to the south-eastern border of the safety pillar in the seam No 504 (Fig. 7).

A total of 52 blastholes were drilled within the rock mass between the coal seams Nos. 504 and 512 from three different roadways. The length of the blastholes ranged from 25 m to 80 m and all of them were drilled with a diameter of 93 mm. Blastholes 501–528 were drilled in a linear layout along the roadways 40 380 and 40 390 (both located in the seam No. 504), with inclination angle of 41° (upwards) and with 7 m of spacing between them (Fig. 7). Blastholes 529–533 were drilled in a fan layout from the end of the roadway 40 390 (located 50 m above seam No. 504) with inclination angles ranging from 4° to 35° from horizontal (upwards). Blastholes 1–14 were drilled in a fan layout from roadway 30 309-4 (located in the seam No. 504) with inclination angles ranging from -58° (downwards) to 29° (upwards). Blastholes 15–19 were drilled in a fan layout from the roadway 40 315 with inclination angles ranging from 8° to 31° (upwards). All blastholes were drilled exactly in the same vertical plane. Blasting parameters are summarized in Table 4.

The blasting was performed in 13 different stages. The number of blastholes fired in each stage varied from 3 to 7. Depending on the blasthole length

and its position, the lengths of the charges varied between 18 m to 60 m and the stemming lengths from 7 m up to 20 m. The amount of explosive fired in each stage ranged between 1130 kg and 2760 kg.

All charges in each stage were fired simultaneously (no delay). The blastholes were charged pneumatically with plastic explosive Perunit 20 and sand was used for the stemming.

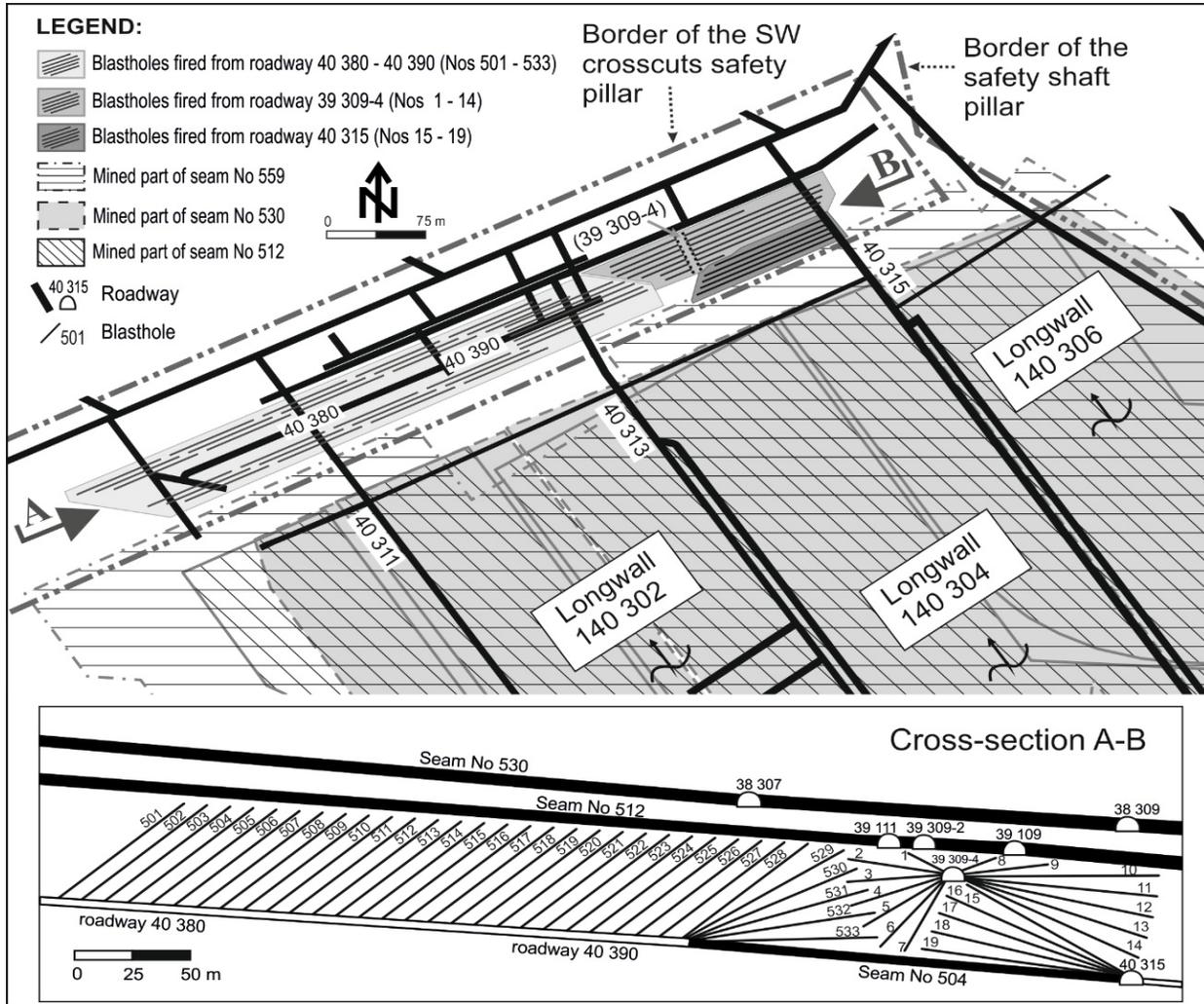


Figure 7: Scheme of the cutting destress blasting carried out in the longwalls 140 302, 140 304 and 140 306 at the border of the SW cross-cuts safety pillar.

Stages Nos. 1–5 were fired before the coal extraction in adjacent longwalls 140 302, 140 304 and 140 306 had started. Stages Nos. 6–12 were fired at a distance of 350 m to 240 m from advancing longwall face 140 302. Stage No. 13 was fired at a distance of 430 m from advancing longwall face 140 304 (longwall 140 302 was already finished). According to registered seismicity in the area, the SE of each blasting stage has been calculated (see previous section). The blasting works at the border of the SWC safety pillar presented different destress efficiency levels. Thus, stages Nos. 7 and 8 were

‘extremely good’ (SE was 6.3 and 7.4), stages Nos. 1–6 and 10–13 were ‘very good’ (SE values ranged from 3.2 to 5.9) and stage No. 9 was ‘good’ (SE was 2.8). These results show an important destress efficiency at the border of the SWC safety pillar, although it was lower than in the two cases presented above. No rockbursts occurred during further advancing of the mining works in the longwalls 140 302, 140 304, and 140 306 after the cutting destress blasting was performed. This fact can be considered as a sign of improvement of the stress conditions in the area surrounding the SWC safety pillar.

Table 4: Destress rock blasting parameters conducted in longwalls 140 302, 140 304 and 140 306.

Stage	Blasthole number (-)	Explosive charge (kg)	Released seismic energy (J)	SE (-)	SE evaluation (-)
1	501-504	1560	1,70E+04	5.2	Very good
2	516-519	1656	1,50E+04	4.3	Very good
3	505-508	1656	1,50E+04	4.3	Very good
4	520-523	1656	1,20E+04	3.5	Very good
5	512-515	1688	2,10E+04	5.9	Very good
6	509-511	1130	1,30E+04	5.5	Very good
7	524-527	1728	2,30E+04	6.3	Extremely good
8	1-7	1488	2,30E+04	7.4	Extremely good
9	12-14	1275	7,60E+03	2.8	Good
10	8-11	1296	1,50E+04	5.5	Very good
11	528-530	1344	1,10E+04	3.9	Very good
12	531-533	1506	1,00E+04	3.2	Very good
13	15-19	2760	2,00E+04	3.5	Very good

7. CONCLUSION

Over the years, different safety pillars have been established in the Lazy Colliery in order to protect important mining infrastructures. Although mining activity is not carried out in these protected areas, coal extraction in adjacent panels can induce undesirable rock deformation and dangerous stress concentration within the safety pillars. Proactive destress measures have been used to avoid these problems when the faces of the longwalls in the seam No. 504 were approaching the central safety shaft pillar, or the safety pillar of the SW cross-cuts. The implementation of cutting destress blasting at the border of these safety pillars has allowed to cut out the rock mass to create an artificial boundary between the safety pillar areas and the longwall areas. This separation has reduced the stress concentrations encountered in the intact rocks of the safety pillar limits. Seismic monitoring showed that for all cases, blasting induced beneficial stress release. The calculated seismic effect of all blasting stages was

evaluated as good, very good, extremely good and excellent. After the cutting destress blasting were performed in the selected areas, coal extraction in the mentioned longwalls finished satisfactorily without any occurrence of rockbursts or other incidents in neither the longwall areas, nor the safety pillar areas. Therefore, the main aims of the cutting destress blasting were achieved.

8. ACKNOWLEDGEMENT

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