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Procedia Engineering 26 (2011) 179 – 194

**Procedia
Engineering**www.elsevier.com/locate/procedia

First International Symposium on Mine Safety Science and Engineering

Destress Blasting in Coal Mining – State-of-the-Art Review

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Abstract

Coal mine workings continue to face the challenges of coal bumps and rockbursts caused by high mining-induced stresses due to high overburden pressures associated with the extraction of brittle, low strength coal seams. Despite of the fact that destress blasting has been applied for almost a century, it is still not a popular choice. This paper presents a state-of-the-art review of destress blasting in coal mining. Information such as geology, rock properties, mining conditions as well as blasting parameters such as blasthole layout, hole length, explosive loading etc. are presented. The paper discusses the main benefits of destress blasting and the evaluation of its effectiveness as a measure to overcome the challenges of high mining-induced stresses causing coal bumps and rockbursts.

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Selection and/or peer-review under responsibility of China Academy of Safety Science and Technology, China University of Mining and Technology(Beijing), McGill University and University of Wollongong.

Keywords: Mining; Coal; Destress Blasting

1. Introduction

It is elementary but important to illustrate that an underground excavation initiates a process of re-equilibrium, which leads to the generation of stresses around the excavation in a manner that free surfaces become planes for principal stresses and experience a bi-axial state of stress condition. The excavation boundaries may experience damage effects due to stresses and these effects for coal mines can be dislocation of rock reinforcement, interbed crossover of laminated roof rock mass, cutter failure, floor heave and/or rockburst/coal bump (Fig 1). These damaging effects are presented in the order of their severity according to the stress level, corresponding strength (uniaxial and poly-axial) at the point of consideration of the stress loading. Excess of the stress level in comparison to the strength and the rate at

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which the excess is attained during the re-equilibrium process is manifested into the different damaging effects as illustrated in Figure 1. A faster rate in obtaining excess stresses will result into rockburst/coal bump. Occurrence of this excess stress over a greater area will increase the severity of the damaging effects. Further, part of the excavation experiences stress concentration and another experiences stress relaxation due to the shape of the opening and in situ stress directions.

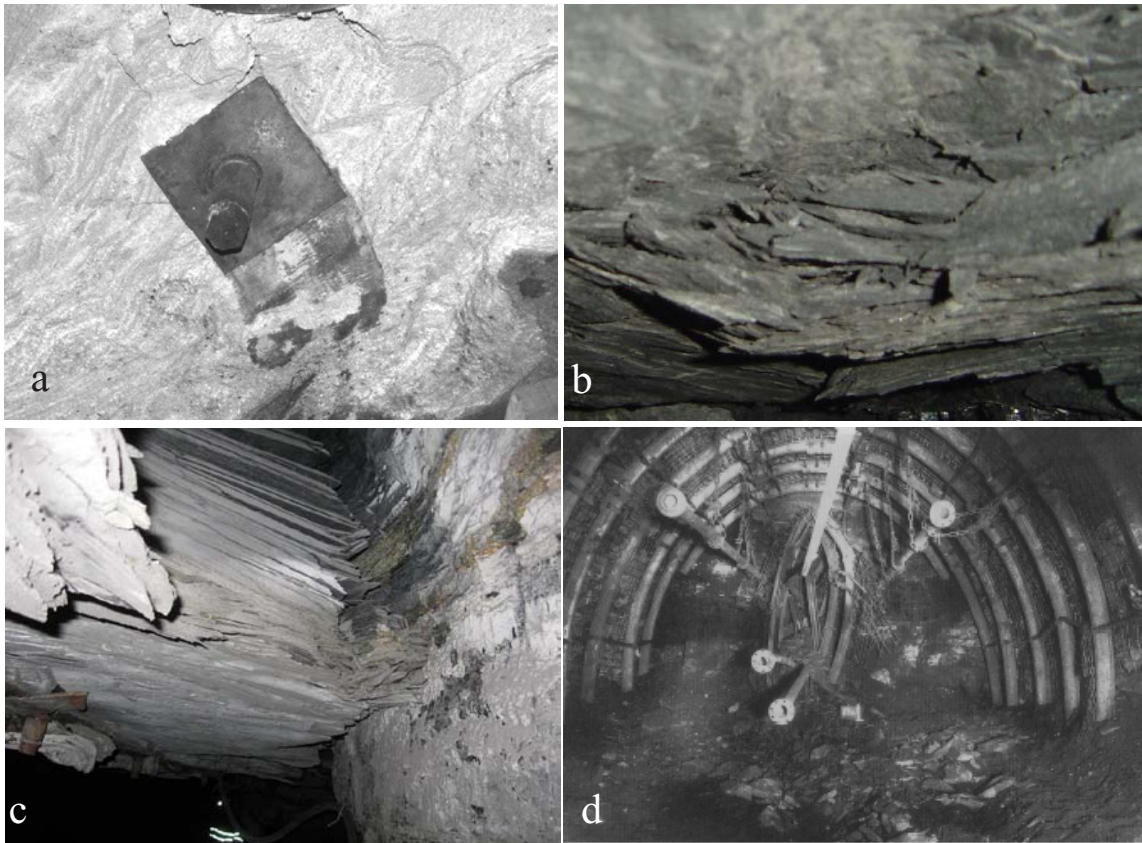


Fig 1. (a) Rockbolt dislocation in an Indian coal mine; (b) Interbed crossover in a coal mine of South Africa [1]; (c) Cutter roof failure in an US coal mine [2]; (d) Rockburst in a German coal mine [3].

Past research for measurement of stresses, understanding of stresses and prediction of the timing when and the rate at which the stresses will be in excess of the strength has been a mixed success. The mining process has, in the meantime, become faster, larger and being done at deeper levels. It is thus necessary that protective measures be evolved to deal with the damaging effects of excessive stresses. Figure 2 illustrates different methods evolved to deal with the damaging effects of excessive stresses and destress blasting is one of the oldest and proactive measures amongst the other methods [4]. The mechanism of destress blasting is not well understood despite of the application of destress blasting in a wide range of mining conditions and objectives.

The paper presents various conditions for which destress blasting is applied for deep coal mines and discusses the possibilities to further improve the method. The application of destress blasting is aimed into the zones of stress concentration in such a manner that the stress concentration zone shifted interior to the rock mass thus leaving a protective barrier between the work force and the stress concentration zone. This mechanism of destress blasting is illustrated in Figure 3, which demonstrate that destress blasting shifts stress concentration zone away from the active working front.

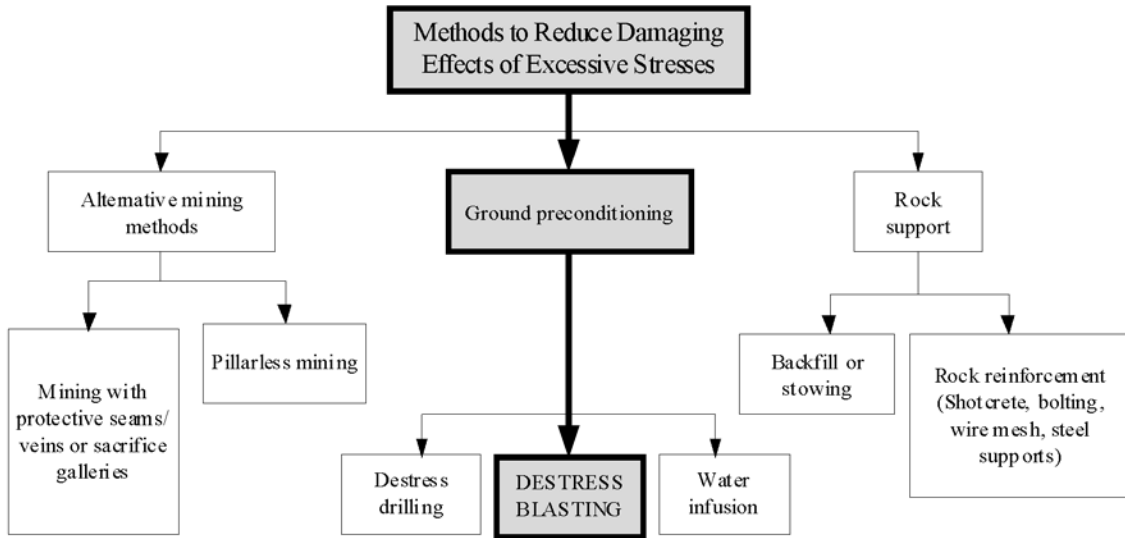


Fig. 2. Methods to reduce damaging effects of excessive stresses [4]

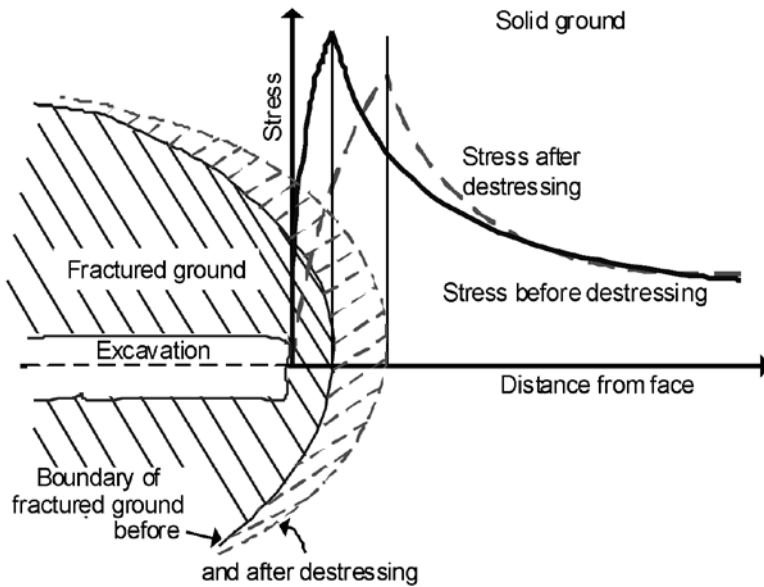


Fig. 3. Geomechanics effects of destress blasting [5]

2. Natural and mining conditions

Hardcoal deposits are mostly complex sedimentary sequences containing coal seams (multiseam deposits) in Upper Paleozoic age. Rocks between coal seams comprise shale, mudstones, siltstones, sandstones and conglomerates. Thickness of coal bearing strata ranges from hundreds to thousands of meters, whereas the thickness of coal seams varies from 1 to tens of meters. The feature most common where cutter roof failure or floor heave occurs is the presence of thinly laminated roof / floor. The feature most common to seams in which rockburst occur is the close proximity to a strong, thick and rigid stratum [3]. These strata consist of sandstones and conglomerates in most coalfields and in rare cases they consist of other types of geological materials and can be defined as competent massive elastic rock [6]. Typical examples of rockburst prone strata are described in Fig 4. Summary of the basic rock properties of carboniferous rocks is illustrated through Table 1 [3, 7]. It is also important to understand that coal bearing strata have very difficult structural tectonic pattern [14] with very complicated natural stress field and combination of these causes stress damages [7, 8, 9, 10].

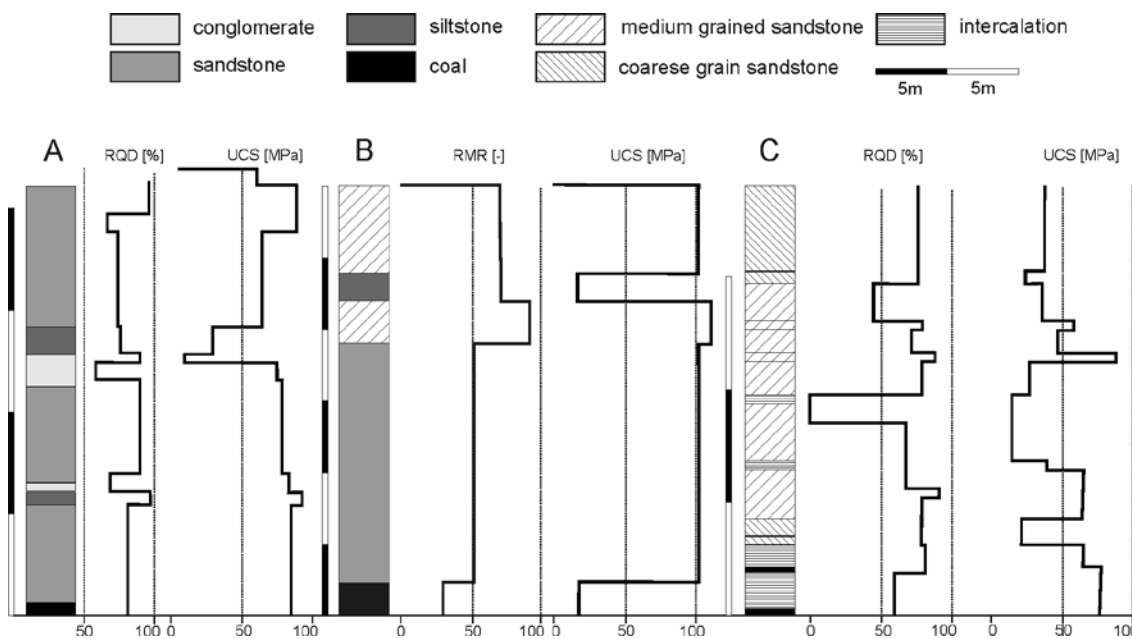


Fig. 4. Typical properties of carboniferous rock mass with competent rock layers (A) Lazy Colliery (the Czech part of USCB); (B) Germany [11] ; (C) Chinakuri Colliery (India) [12]

Table 1. Rock properties*

Rock	UCS [MPa]	RQD [%]	Bed thickness [m] (competent rocks)
Coal	10–30	-	-
Mudstones	35–65	-	-
Siltstones	40–150	60–90	5–10
Sandstones	50–170	60–90	10–100
Conglomerates	40–140	60–90	5–20

*Generalized data from Czech, German, Indian, Polish, Ukraine and USA Collieries [3, 7, 11, 52]

Mining conditions influence the rock mass response and stress concentration. Some of these conditions are listed below.

- mining within more than one coal seams separated to each other by 3m to about 100m,
- extraction thickness and size of the openings,
- protective / unmined pillars in coal seams,
- part unmined overlying seams,
- advance rate of mining,
- different advance direction in overlying seams, and
- improperly superimposed mining layouts in multi-seam mining

Typical example of complicated mining history is presented in Fig. 5, which was published by Dvorsky et al. [47]. Figure 5 represents time sequence of mining in area of 4th mining block in CSA Colliery in the Czech part of the Upper Silesian Coal Basin (USCB). The scheme of mining in the level of seam No. 530 which was mined with many overlying seams in different directions (Fig. 5 shows only four of them) is illustrated. Overlying seams had many unmined pillars that were left in the central part of the mining block due to a tectonic fault occurrence. The mining conditions were further compounded due to changing

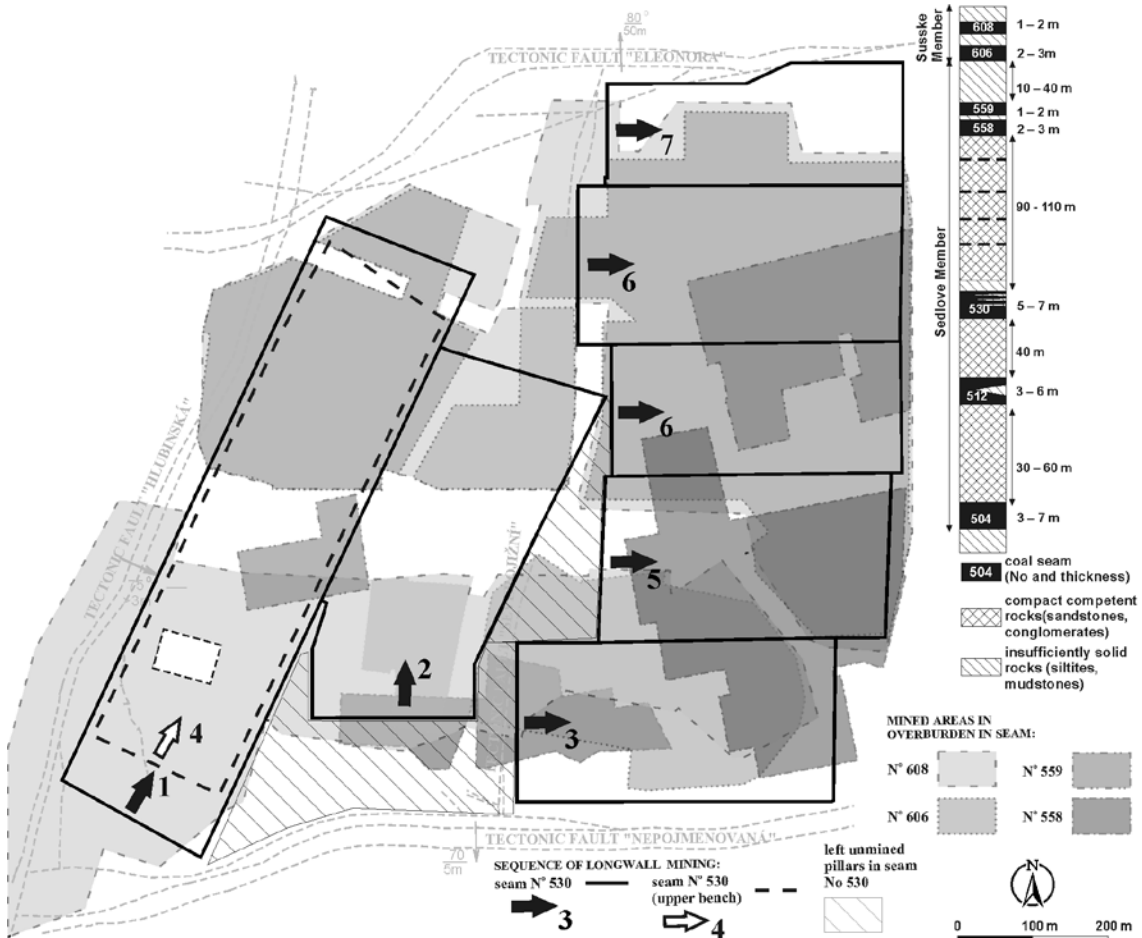


Fig. 5. Schematic map of time sequence of mining of particular longwalls in area of 4th mining block (seam No 530) of CSA Colliery in the Czech part of the USCB; adjusted after [47].

of mining direction in west and east part of mining block. This complicated mining situation together with very difficult natural conditions caused many rockburst while mining the seam No. 530 [47, 15].

Numerous mining case studies of excessive damages from induced stresses can be presented from many mining regions across continents, such as Australia [16], Czech Republic [15, 17, 18, 47], Germany [3, 11, 19, 20], Poland [21, 22, 23, 37], USA [24], China [25, 26] and India [27].

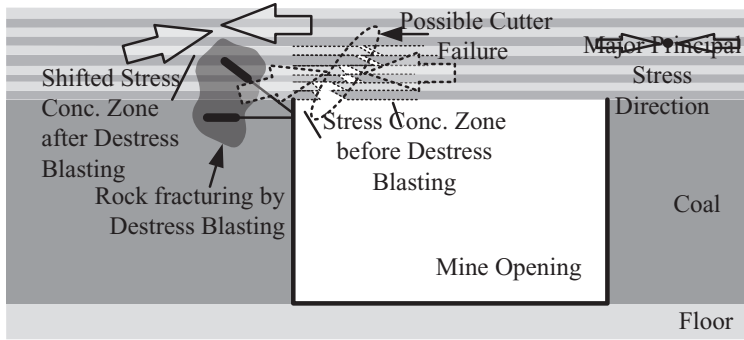
3. Destress blasting as proactive measure

Destress blasting in coal seams or immediate roof and floor rock mass has been adopted to manage cutter roof failure, floor heave and rockburst/coal bump. The objective has been to shift excessive induced stresses to the interior rock mass and to provide a protective barrier surrounding the excavation. Three typical conditions, for which destress blasting has been adopted, are illustrated in Figure 6. These use destress blasting to avoid cutter roof failure, floor heave and rockburst. Major principal stress for the cases shown in Figure 6 is horizontal except for the case of longwall mining where major principal stress from vertical direction is the cause of concern. These cases typically use farthest one third length of the borehole charged with permitted explosive (single cartridge per metre of the charge length) and borehole length designed such that the explosive column begins at least 3 m or 1.5 times the excavation height from the borehole collar [3]. The condition under which destress blasting is required and the location of destress blasting is determined from drilling rate and noise of test drill holes. The effectiveness of destress blasting is measured from change in support pressure and rate of convergence of roof/floor rock mass. Successful application of destress blasting under such conditions requires that it shall be practiced on regular basis and be a part of routine mining cycle.

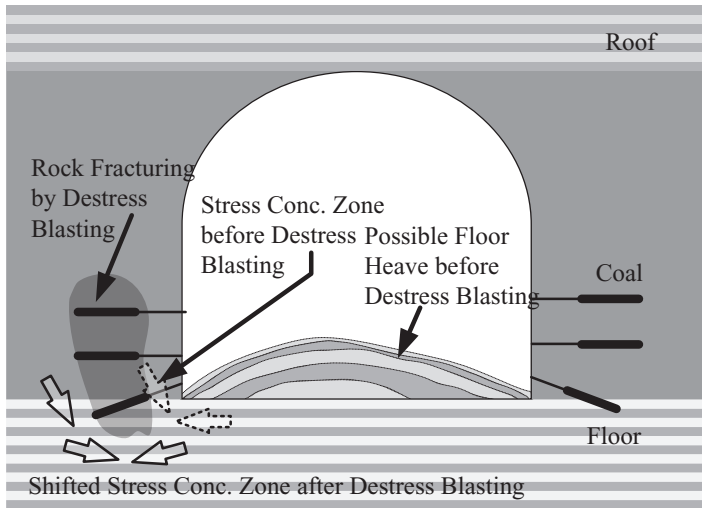
Kexin [25] and Xia et al. [26] describe application of destress blasting to control floor heave for deep coal mines in China. The destress blasting involve a pattern and objective consistent with the Figure 6(b). Details of the pattern reported by Kexin [25] is given in Table 2. The destress blasting program reported to be a success in the mine.

Table 2 – parameters of borehole pattern for destress blasting in the test gallery [25]

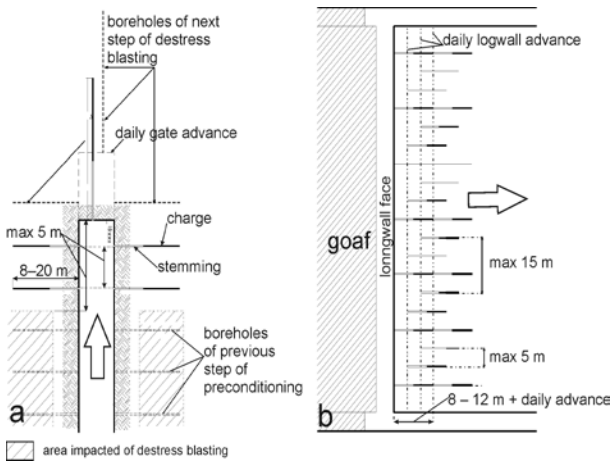
Test section	pattern	Row spacing, m	Layout		Spacing, m	Borehole		Charging		Mud stemming, m		
			Toe spacing, m	Column spacing, m		Depth, m	Orient-ation	Charging, m				
1	2 row, 3 hole in flower pattern	2	1.2	0.4	1.2	4.7			Left	1.6	Left	3.1
									Right	1.9	Right	3.8
2	2 deep hole, 1 shallow hole	3	0.8	0.4	0.8	Deep hole	4.2	⊥ to wall	Deep hole	1.5	Deep hole	2.7
						Shallow hole	3.2		Shallow hole	0.7	Shallow hole	2.5
3	2 row 3 hole in flower pattern	2	0.7	0.7	1.0	4.1			0.9-1.8		3.2-2.3	
4	2 line row	2	0.7	0.7	0.7	4.3			0.4-1.2		3.9-3.1	



(a) System of destress blasting to limit cutter roof failure



(b) System of destress blasting to limit floor heave



(c) System of destress blasting to limit rockburst in gate driving and longwall mining

Fig. 6. Destress blasting as proactive measure for different objectives

Destress coal blasting is similarly used to alleviate rockbursts problems in Polish and Czech Collieries but also in German collieries in the past [18, 19, 28, 29, 30, 31, 32, 33]. A typical destress blasting practice set-up is shown in fig. 6(c) [29]. Length of boreholes used for destress blasting depends on size of protective area which is created ahead of a face and this is a function of thickness of coal seam, size of pillars, mining depth and locked-in stresses in immediate roof rocks (principles are presented in Figure 3).

In Polish collieries, length of boreholes is usually up to 10 m, diameter of boreholes do not exceed 80 mm (usually 42 mm). Generally we can quote that small charges (max. 2.5 kg safety explosive per borehole) are used for boreholes indicating excessive stress state. However, consumption of blasting material on 1 m of longwall advance is reported about 80 kg [28]. Combined system is frequently used in driving – destress blasting and cut blasting together where length of boreholes and explosive charge are smaller [28], length of boreholes from 1.2 to 2.4 m and explosive charge is from 300 g to 1200 g per borehole. Maximum waiting time after destress blasting in coal seam is 30 minutes.

In Czech Collieries the length of borehole is larger (up to 20 m), diameter of boreholes (42 mm) and spacing of boreholes (max. 5 m in driving of roadways, max. 15 m in logwall face) are strictly given. Explosive charge is larger (from 2.5 to 7.5 kg per borehole, i.e. 50 % – 60% length of borehole). Maximum weight of explosive charge is 180 kg per destress blasting stage. Combination of destress blasting in coal seams and destress drilling are sometimes used [45]; in driving destress boreholes in the face and destress blasting in sides of gates; in mining destress boreholes from gateways and the rest of the longwall face – destress blasting. Typical example of destress blasting in Czech collieries is presented in Figure 6(c).

In German collieries, destress drilling (or slotting) is preferred over destress blasting in most cases. Rockburst phenomena are observed in coal seams only, and destress drilling is believed to be more effective [46]. It is noteworthy that the thickness of coal seams in German collieries generally does not exceed 3.5 m.

Generally, coal deposits are found in multi-seam separated from each other by 3m (termed as contiguous seams) to few tens of meters and they worked in sequence from top to bottom except contiguous seams. Often enough, part of the upper seam is not mineable and is let behind. Mining of the seam below the unmined portion of the upper seam may pose strainbursting hazards. Such a situation demands the application of destress blasting prior to the mining of the lower seam [e.g. 2, 35, 47].

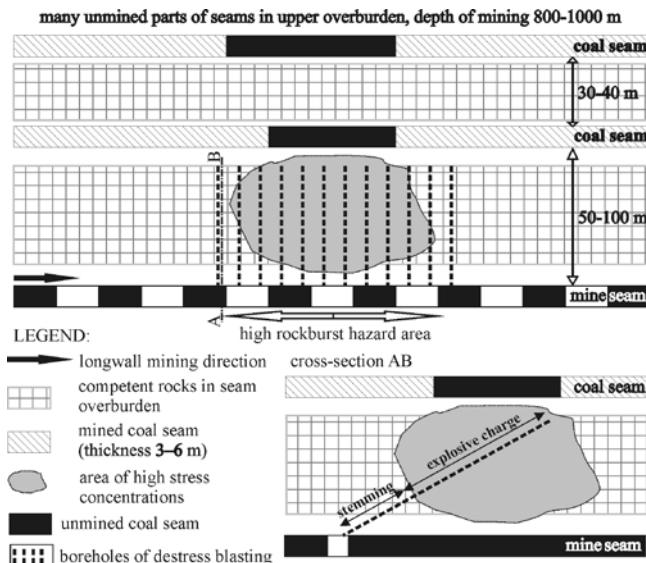


Figure 7. Simplified model of destress blasting application [36]

Application of destress blasting under such conditions has been in practice in Czech [36, 45, 47, 48] and Poland [22, 23, 28] and is termed "preconditioning" as destress blasting is practiced much earlier than mining. The simplified conceptual model of destress blasting application as preconditioning is shown in Figure 7 [36].

Thus, two main types of rockbursts are distinguished according to their origin and mechanism. They are: rockburst initiated in the coal seam or its vicinity and rockburst initiated outside the coal seam, mostly in highly competent roof. To protect against rockbursts in the coal seam, active measures are applied in the vicinity of mine workings, whereas to eliminate unfavourable stress conditions outside the coal seam it is necessary to apply passive protection of potentially endangered mine workings. We can generally describe the preconditioning system as a system of long holes which are drilled in adjacent rocks of coal seams. Preconditioning is designed according to the following specifications[36].

- Boreholes drilled usually from the gates.
- Boreholes diameter 75–105 mm.
- Inclination of boreholes up to +30°.
- Spacing of boreholes 5–12 m.
- Pneumatic charging of explosives into boreholes (in cartridges).
- Use of rock explosives.
- Simultaneous blasting without delay.
- Blasting of explosives at a distance of 30 m to 100 m from the longwall face in the region of expected stress concentration.

Maximum waiting time after destress blasting in adjacent rocks depends on the dilution of blast-induced fumes in the mine and registered seismic activity. Waiting time is from 45 to 60 minutes. Destress blasting in adjacent rocks of hardcoal seams is not the most commonly used system of coal rockburst prevention.

Destress blasting as a rockburst control technique comes from deep South African ore mines. We can generally describe main goals of destress blasting as:

- Softening of the competent rock layers and reducing their effective modulus of elasticity,
- Stress release.

Using system in the Czech Collieries, which example is presented below, is a unique European system in difficult stress conditions in rock mass we can describe it widely. The system of destress blasting has been used for 30 years and with increasing mining depths, it has gained importance [36].

An example of destress blasting as preconditioning is presented in Fig. 8 which has been applied in CSA colliery of the Czech Republic [17]. The proper destress blasting drill holes were drilled upwards from (+20°) to (+28°) from coal seam level No 530 located within depth range of 860 m up to 890 m below Earth surface. The lengths of holes varied from 30 m to 80 m. In view of designed parameters and the destress blasting task the borehole diameters of 75 mm and 93 mm were selected. Perpendicular distance between the drill holes of (1) and (2) was 10 m up to 15 m and between the drill holes of (3) was 10 m at maximum. The drill hole bottoms were situated at a distance of about 30 m above top part of coal seam No 530. For drill holes the plastic explosive in charges as well as pneumatic sand stemming were applied. The lengths of particular charges varied from 15 m up to 50 m and the lengths of sand stemming from 15 m up to 30 m. All charges in each stage were simultaneously fired without using delays. Weight of particular charges varied according to applied diameter and length of drill hole from 60 kg up to 400 kg per hole. In particular stages the groups of 2 – 6 drill holes with total charges of 552 kg up to 1440 kg were blasted. 27 stages of destress blasting were realized during the extraction of longwall No 14 735, i.e. from November 2003 until June 2004. A total amount of 27,960 kg explosives was blasted in 120 drill holes. In all stages a greater seismic energy was released than it would correspond to working performed by explosive at specific physical-mechanical conditions.

Similar system of destress blasting is used in Polish collieries [23, 28, 37], length of boreholes is in the range of 12 to 60 m but weight of explosive charge is smaller (according to length of boreholes 40 – 150 kg). Spacing of boreholes is larger (20 – 40 m). Sometimes the goal is to create fractures around the blasted holes. Directional fracturing technique has been developed in Poland [49, 50]. This technique is based on the concept of hydraulic fracturing but has adjustment for destress blasting. The objective is to create fractures perpendicular to borehole axis. Maximum waiting time after destress blasting is much longer than in Czech collieries (up to several hours).

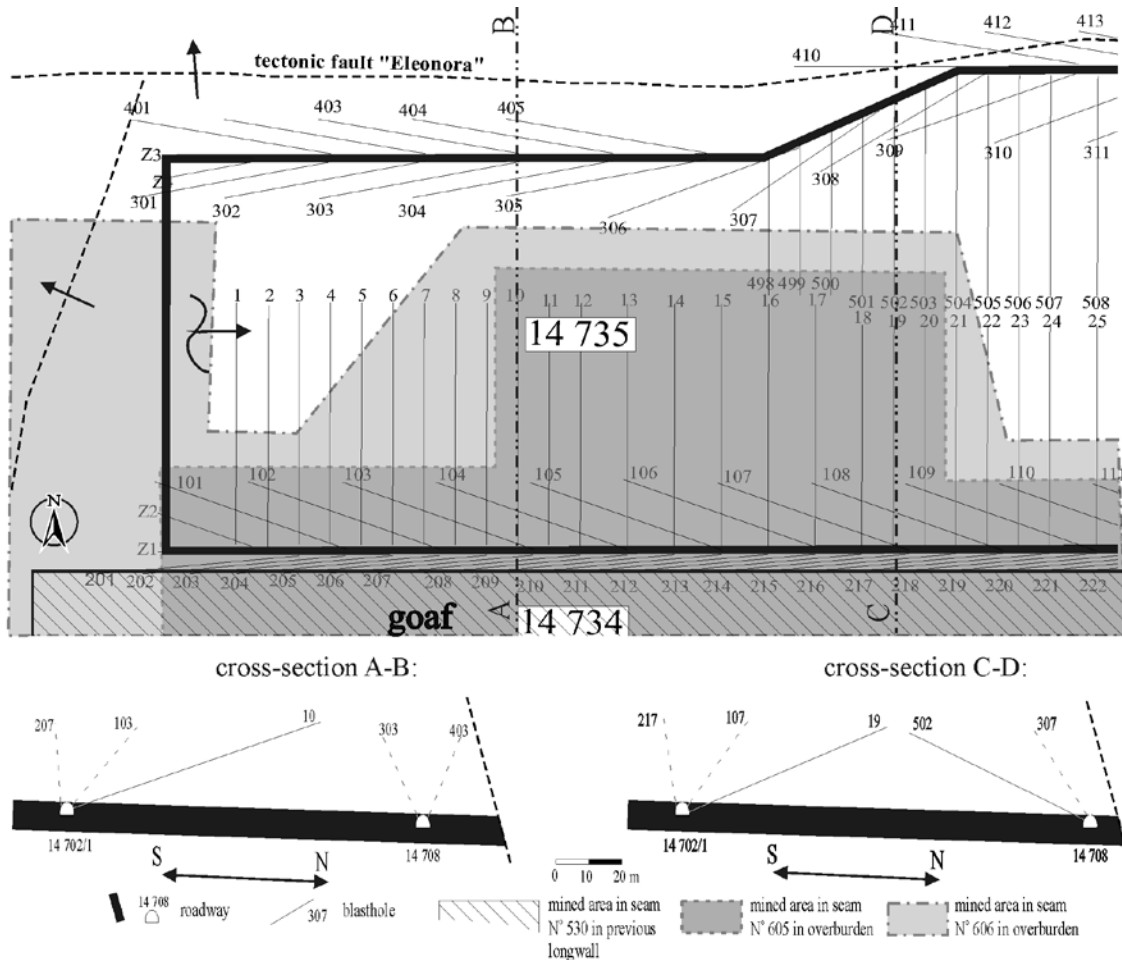


Fig. 8. Scheme and situation of destress blasting in area of longwall No 14 735 in seam No 530 at CSA Colliery [17]

4. Evaluation of effectiveness

Properly designed and realized destress rock blasting (location and spacing of boreholes, diameter of boreholes, length of charge, number of fired boreholes, total explosives charge, etc.) shall reduce the strength and deformation properties of rock mass and thus shift high stress concentration farther interior into the rock mass. Evaluation of effectiveness of destress blasting is thus attempted using different

approaches. We will take here a liberty of describing the effectiveness evaluation approach as being done for non-coal mines too in order to develop a better approach for coal mine applications.

Effectiveness for destress blasting for the case of cutter failure is measured from visual observation. In case of floor heave, the effectiveness of destress blasting is measured in terms of decrease in rock mass deformation and deformation rate. Kexin et al [25] and Xia et al. [26] describe decrease in rock mass deformation after successful application of destress blasting in a Chinese coal mine. Figure 9 illustrates long term measurement of side walls and floor movement characteristics before and after destress blasting in the Chinese coal mine. Various attempts have been made to ascertain effectiveness of destress blasting as applied to alleviate rockburst problems and some of them are described below.

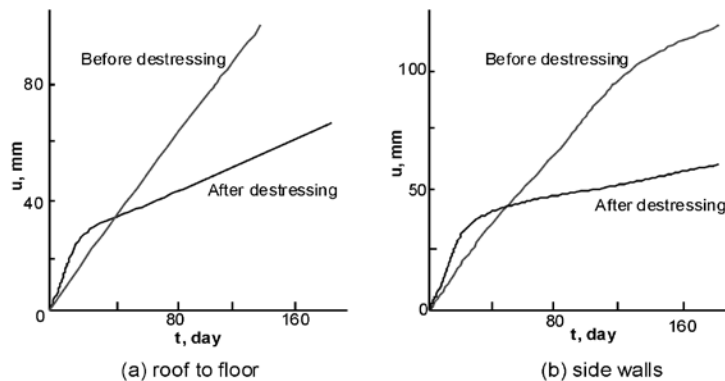


Fig. 9. Convergence monitoring in a coal mine roadway [25]

Change in stress parameters before and after destress blasting [35, 38, 39] and modulus parameters [40, 41] has been monitored both in coal and non-coal mines as it is believed that the objective of destress blasting is to reduce the critical stress parameters and induce reduction in modulus values so that the rock mass shall not carry critical stress level. Fig. 10 represents measurement of stress change due to destress blasting in tabular gold deposits in South Africa. Such measurements are troubled with inexplicable results. Attempts have also been made to characterize the effectiveness of destress blasting by the calculation of seismic energy released concurrent to destress blasting application as it is conceived that release of higher energy than contained by the explosives is a manifestation of release of strain energy stored in the rock mass [36, 42]. The problem, however, with the application of this methodology is that majority of rockbursts are concurrent to the blasting, irrespective of routine blasting or destress blasting. Stress release is evaluated using calculated seismic effect – SE [51, 42]. It is based on statistical interpretation of the data of SE distribution [42]. The degree of stress release due to destress blasting can be divided, on the basis of SE calculation, into insignificant, good, very good, extremely good and excellent (see Table 3). The SE of destress rock blasting is the ratio of seismic energy released in the rock mass when blasting to the considered energy of the particular detonated charge:

$$SE = \frac{E_{\text{Seis}}}{K \cdot Q} \quad (1)$$

where E_{Seis} = seismic energy in J; Q = weight of explosive charge in kg; and $K = 2.1$ (for the natural conditions of rock mass in the Czech part of the USCIB). The released seismic energy in the rock mass E_{Seis} is evaluated from seismic monitoring.

Table 3. Evaluation of stress release in rock mass (stress release) [42]

Seismic effect	Evaluation of Seismic effect (SE)
<1.7	Insignificant
1.7<SE<3	Good
3<SE<6	Very good
6<SE<12	Extremely good
SE>12	Excellent

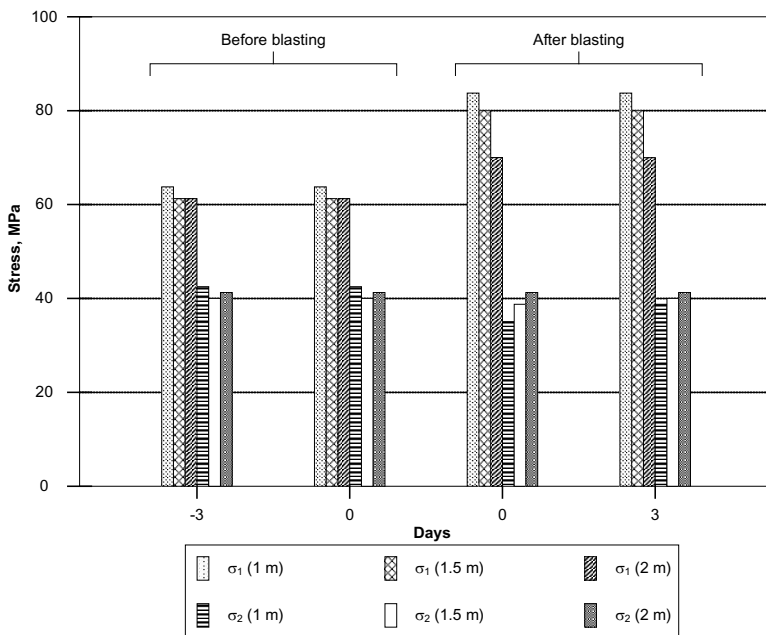


Fig. 10. Strain gauge measurements of a destress blasting test [39]

Geophysical methods have also been attempted to characterize destressing effects [44]. Fig. 11 illustrates the results of a seismic tomography used to measure change in P- and S-waves in a metal mine stope due to destress blasting as change in these parameters are indicators of modulus reduction of rock mass. Such attempts are further extended to develop empirical relations to measure effectiveness of destress blasting [43]. Andrieux & Hadjigeorgiou [43] presented an empirical method whereas ratings of nine different geotechnical and operational parameters are estimated on a scale of 0 to 1 to assess the effectiveness of a large scale destress blasting (Table 4) in a deep underground mine pillar in a manner similar to rock mass characterization method.

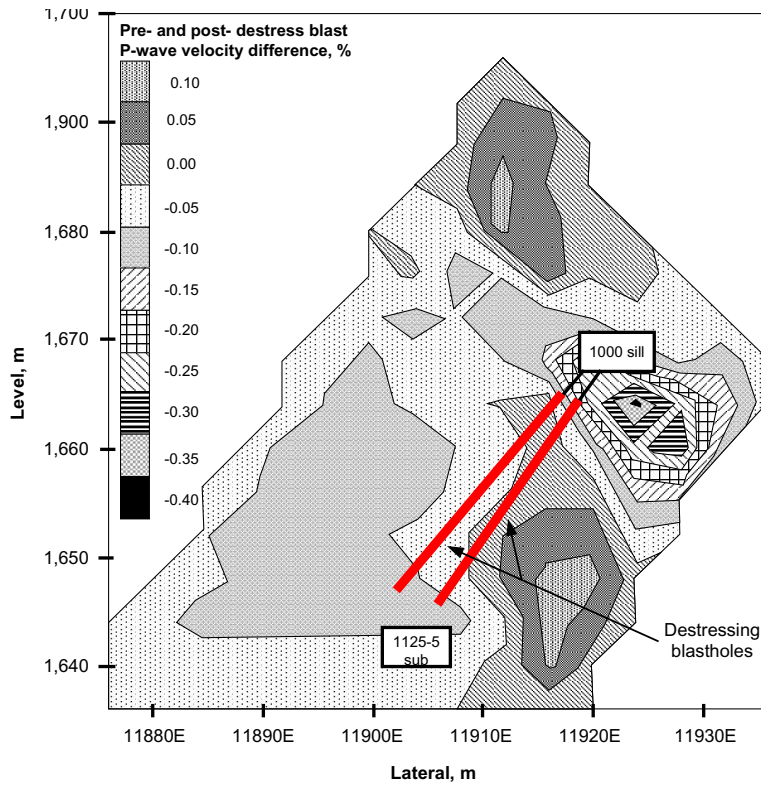


Fig. 11. Damage zone identification with pre- and post-destress blast seismic tomography in Brunswick Mine, Canada (Longitudinal-section) [44]

Table 4. Parameters used to characterize large-scale choked pillar destress blasting - RES interaction matrix [43]

Parameter	Associated measurable properties
Stiffness of the rock mass	$E_{\text{Laboratory}}$, Rock Mass Rating (RMR)
Brittleness of the rock mass	B_1 (defined as $\sigma_{\text{C Rock mass (uniaxial compressive strength)}} / \sigma_{\text{T Rock mass (tensile strength)}}$)
Degree of fracturing of the rock mass	RMR
Proximity to failure of the rock mass	$\sigma_{1 \text{ actuals}} \sigma_{3 \text{ actuals}}$ Hoek–Brown failure criterion (at the rock mass scale)
Orientation of the destress blast	$\sigma_{1 \text{ actuals}}$ azimuth of the destress blast
Width of the destress blast	Burden, blasthole diameter and number of blasthole rings used
Unit explosive energy	Explosive density, AWS (absolute weight strength), blasthole length and diameter, collar length, burden and spacing, charge coupling ratios
Confinement of the explosive charges	Toe breakthrough, collar and toe lengths, collar and toe stemming
Result of the destress blast	Stress level reduction, based upon instrumentation and measurements. Case where the rock properties are at the rock mass scale.

5. Conclusions

Destress blasting is an important technique for managing hazards of strainbursts due to excessive mining induced stresses. The technique can be applied to coal rocks either as a proactive measure or as a preconditioning tool before panel extraction. A wide range of applications of destress blasting is presented

in this paper and it can be summarized that destress blasting, if properly applied, can help mitigate the problems of high stress and associated coal bumps and rockbursts. With the increase of production rates at greater mining depths in recent years, the importance of destress blasting is growing as a mine safety tool. While many lessons have been learned through the successful application of destress blasting in the field, such lessons cannot be easily generalized, as underground mines are never alike. Careful consideration of the mining system and rock mass conditions is required whenever there is a need to design a new destress blasting pattern.

Acknowledgements

This research is financially supported by the Grant of Ministry of the Interior of the Czech Republic (project No. VG20102014034). The authors would like to thank colleagues Jiri Ptacek, Petr Konecny and Kamil Soucek for their valuable recommendations. The views expressed in this paper are of authors and shall not be construed views of respective institutes.

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