

## Powered support selection for longwall workings in dynamic load conditions

Stanisław Prusek<sup>a</sup>, Sylwester Rajwa<sup>b</sup>, Andrzej Walentek<sup>b</sup> and Wojciech Masny<sup>b\*</sup>

<sup>a</sup> General Director of Central Mining Institute, Plac Gwarkow 1, Katowice, Poland.

<sup>b</sup> Department of Extraction Technologies and Mining Support, Central Mining Institute, Plac Gwarkow 1, Katowice, Poland.

### ABSTRACT

Currently in Poland hard coal is mined in two Coal Basins namely Upper Silesian and Lublin. In Poland, there were 30 underground hard coal mines that produced 72.5 million tons of coal in 2014. For underground hard coal (steam coal and coking coal) seam extraction, the longwall method is used and retreat longwalls with natural roof caving in the gob are the most common. Currently it is estimated that about half of the hard coal output in Poland originates from seams located in areas of rock burst hazard. In this paper, the most important data concerning the geological and mining conditions in Polish hard coal collieries are presented with particular emphasis on tremors, rock bursts, and fatalities. Moreover, the article shows information about seismic events which occurred between 2003 and 2012 in underground mines belonging to one of the coal companies in Poland. In addition, negative consequences of those dynamic phenomena in the longwall workings are described. In order to avoid damage of powered supports in geomining conditions where dynamic phenomena occur, different types of protective means are applied. In the paper the methodology of assessing the powered support yield ability is described.

### 1. INTRODUCTION

In Poland the production of hard coal (i.e. steam coal and coking coal) is conducted in increasingly harder geological and mining conditions, resulting from the still growing depth of mining operations and numerous former exploitations in the mined longwall panels in the form of edges and/or residues. These factors generally increase the level of natural hazard in Polish mines. A very important one is rock burst hazard associated with the occurrence of rock mass tremors. The hazard directly affects both personnel safety and the continuity of coal production.

Rock mass tremors induced by mining operations may result in rock bursts or decompressions. According to Polish regulations (Ordinance of the Minister of Internal Affairs and Administration of 2002) a rock burst is defined as a dynamic phenomenon caused by a rock mass tremor which results in destroying or damaging a working, or its fragment, leading to the complete or partial loss of its functionality or making it dangerous to use. While decompression is defined as a dynamic phenomenon caused by a rock mass tremor which causes damage to a mine working (or its fragment), it does not result in loss of functionality nor renders it unsafe for personnel.

Hard coal mining operations, in areas where dynamic phenomena occur, requires considering both static and dynamic load while designing support both for headings and longwalls, as, when a tremor occurs, there is an increase in the value of load exerted on a support, and the main task of a properly designed support ought to be maintaining the stability of a

mine working and providing the proper level of safety for personnel.

This article presents basic information concerning the hard coal mining industry in Poland, with special attention to data on rock mass tremors. Then, the most common forms of damage to a longwall powered support resulting from dynamic phenomena are characterised. There is also information on a method applied in Polish mining industry to secure a powered support against effects of additional load resulting from rock mass tremors.

### 2. GENERAL CHARACTERISTICS OF HARD COAL MINING IN POLAND

Hard coal deposits in Poland are mined in two coal basins, namely Lublin Coal Basin (LZW) and Upper Silesian Coal Basin (GZW). Lublin Coal Basin is located in the south-eastern part of Poland, near the border with Ukraine. At the moment one coal mine - LW Bogdanka, operates there. The Upper Silesian Coal Basin is located in the south of Poland near an urban agglomeration, with Katowice in its centre. Mining operations in the Upper Silesian Coal Basin have been conducted for over 200 years.

In 2014, there were 30 underground hard coal mines operating in Poland, which produced 72.5 million tons of coal. The basic hard coal mining system is the longwall system with single gateroads. In 2014, there were 118 operating longwalls (Cybulski and Malich 2015). The average depth of mining operations was slightly over 700 m. In all the mines coal is produced in multiple seams which often

\*Corresponding author – email: w.masny@gig.eu

results in an increase in rock burst hazard due to influences of former exploitation like edges or residues of previously mined seams. There are also other hazards in Polish mines: seismic, caving, gas, dust, water, climate, radiation and fire.

In the conditions of the Polish mining industry in longwalls with roof cave-in, two-legged shield supports with a lemniscate system are most common. In the type of support, two-stage legs, more seldom one-stage ones with mechanical or hydraulic extenders, are applied. The inside diameter of the legs is usually between 200 and 250 mm. Recently, there has been a tendency to increase the inside diameter of the leg casings to 300 mm and more, which results in the necessity to increase the section pitch to 1.75 m. An increase in setting load and yield load of a section is tightly associated with deteriorating mining conditions and its aim is to provide good conditions for supporting the roof in a longwall. The most numerous group of powered supports are the ones of minimum height ranging between 0.8 and 1.2 m, and maximum between 3.1 and 3.6 m. Supports of higher operation height range (up to 5.0 m), are rarely used (Rajwa et al. 2009).

Between 2003 and 2014 hard coal mining operations in the Upper Silesian Coal Basin resulted in approximately 14,000 tremors of seismic energy  $E \geq 10^5$  (local magnitude,  $M_L \geq 1.7$ ) and 32 rock bursts which caused material and personnel losses. In recent years, 19 tremors have had energy  $E \geq 10^8$  J, and two had  $E \geq 10^9$  J (Stec 2015).

Table 1 presents coal production in Poland between 2003 and 2014, including production in seams threatened by rock bursts, and the number of

rock bursts, accidents, and length of damaged workings in running meters (Patyńska 2015).

Data presented in Table 1 show that in 2003–2014 hard coal production decreased from slightly over 100.0 million tons to 72.5 million tons. In the analysed period, between 39% and over 50% of coal was produced in seams with rock burst hazard. As a consequence of the rock bursts a total of 520 metres of mine workings was destroyed, and approximately 3,600 metres of mine workings was damaged.

### 3. MOST COMMON TYPES OF DAMAGE TO POWERED SUPPORT CAUSED BY ROCK BURSTS AND DECOMPRESSION

Within the framework of the project acronymed I<sup>2</sup>Mine titled “Innovative Technologies and Concepts for the Intelligent Deep Mine of the Future”, realized by the Central Mining Institute, consequences of rock bursts and decompressions which occurred in 2003–2012 in all the coal mines of Kompania Węglowa S.A (KWSA), the biggest producer of hard coal in the European Union, were analysed. In the period, in KWSA’s coal mines there were 18 rock bursts and 14 decompression events. It was observed that 76% of the rock bursts and decompression events occurred during mining operations in longwall panels, 24% of them occurred while driving roadways. Consequences of rock bursts and decompression, which coincided with longwall operations, were mainly apparent in gateroads (49% of cases). Moreover, in 31% of cases the damage was observed in longwalls themselves and in 20% in other adjacent mine workings.

Table 1: Total coal production, including production in seams threatened by rock bursts, accident rate, number of rock bursts, number of accidents, and length of workings damaged by rock bursts in 2003–2014 - (Patyńska 2015).

Year	Total production		Production in seams threatened by rock bursts	Accident rate (accidents/production)	Number of rock bursts	Accidents related to rock bursts		Consequences in workings	
	million tons	% of total				fatal	other (serious and light)	destroyed and collapsed (m)	damaged (m)
2003	100.40	41.8	40.9	0.18	4	2	16	110	145
2004	96.99	39.2	39.4	0.11	3	0	11	0	358
2005	99.50	41.0 <sup>1)</sup>	41.2 <sup>1)</sup>	0.13	3	1	12	0	270
2006	94.50	42.15	44.6	0.25	4	4	20	0	> 510
2007	87.40	44.6 <sup>1)</sup>	49.43 <sup>1)</sup>	0.11	3	0	10	0	530
2008	83.60	41.9 <sup>2)</sup>	50.12	0.31	5	0	26	0	710
2009	77.50	34.3 <sup>3)</sup>	43.8	0.06	1	0	5	0	101
2010	76.10	35.8 <sup>4)</sup>	47.04	0.18	2	2	12	30	87
2011	75.50	34.2 <sup>5)</sup>	45.36	0.08	4	1	6	0	168
2012	79.20	37.60	47.47	0.04	1	1	2	170 <sup>1)</sup>	210 <sup>1)</sup>
2013	76.47	36.90	48.25	0.07	1	0	5	50	113
2014	72.50	36.00	49.66	0.00	1	0	0	160	390

<sup>1)</sup> - approximated data

Table 2 shows numerical values of the most important parameters characterising dynamic phenomena. Load coefficient  $n_{tz}$ , presented in Table 2 is calculated with the following empirical dependence presented by Biliński (2005).

Table 2: Basic parameters of rock bursts and decompression occurring in Kompania Węglowa S.A.'s mines, 2003-2012 (Prusek, Masny 2015)

Parameter	Phenomenon			
	Rock burst		Decompression	
	min	max	min	max
Seismic energy of tremor, (J)	7.0E+05	2.0E+08	4.0E+04	8.0E+07
Peak particle velocity $PPV$ , (m/s)	0.064	0.598	0.014*	0.353
Depth of mine working, (m)	630	1,085	545	1,130
Distance between tremor hypocentre and tremor effects, (m)	24	567	37	572
Vertical distance between tremor effects and tremor-prone layer (m)	3	245	10	460
coefficient $n_{tz}$	1.10	1.51	1.05	1.53

\* PPV is estimated due to low accuracy to locate tremor hypocenter

Data presented in Table 2 show that workings and their support were damaged at seismic energy of tremor of 4.0E+04 J and relatively low load coefficient  $n_{tz}=1.05$ . A probable cause of such a situation in such cases was significantly high static load exerted on a support prior to a tremor, just before the dynamic phenomenon.

The calculated values of peak particle velocity  $PPV$ , being an empirical criterion of assessing stability of workings subjected to the influence of mine tremors, or the analysed 18 rock bursts and 14 decompression events were contained between 0.014 m/s and 0.598 m/s. The values are confirmed by Mutke's (2008) research. He determined that in the conditions of Polish hard coal mines workings lose stability when  $PPV$  is between 0.050 and 1.000 m/s.

The conducted analyses of dynamic phenomena in KWSA's mines enabled determination of the most common forms of damage to workings and support in longwalls, see Figure 1.

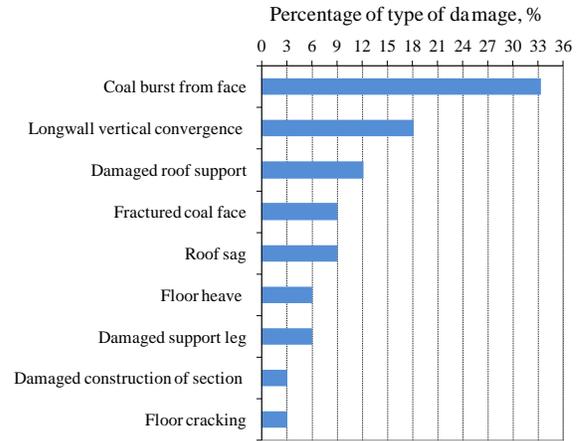


Figure 1. Types of damage to longwalls and shield support caused by dynamic phenomena, % (Prusek and Masny 2015).

Following the data presented in Figure 1, we can conclude that in longwalls, due to the dynamic influence of the rockmass, coal bursts from the sidewall into the working – 33% were most common (Figure 2a). In over 18% of longwalls there were roof sags (Figure 2b).

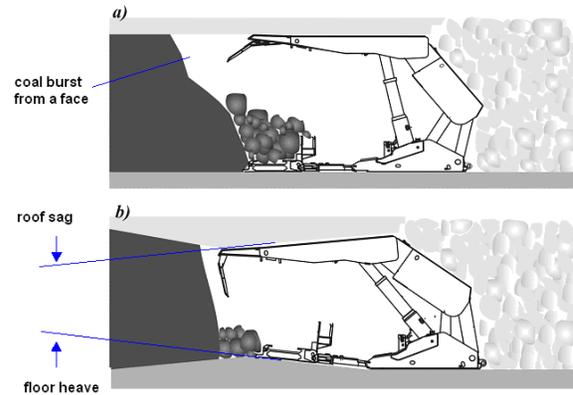


Figure 2. Characteristic forms of damage to longwall caused by rock bursts or decompressions (Prusek and Masny 2015).

Coal bursts from sidewall into a working (Figure 2a) result from the fact that the coal face, usually of the lowest strength parameters, is the largest surface of a longwall which is not secured with a shield support. Only in two of the analysed rock bursts and decompression events was a coal burst additionally accompanied by roof sag in the tip to face distance. Another characteristic form of damage observed in longwalls, associated with dynamic phenomena, is convergence, as it is presented in Figure 2b. More often it is caused by a floor heave than by a roof sag (Prusek and Masny 2015).

Referring to the most common types of damage to powered supports in a longwall, it can be concluded that they affect mainly: legs, valve batteries, spherical head connections between the legs and canopy/base, and lemniscate bars. Hydraulic legs are most often torn or their rod is broken, as shown in Figures 3a and 3b.

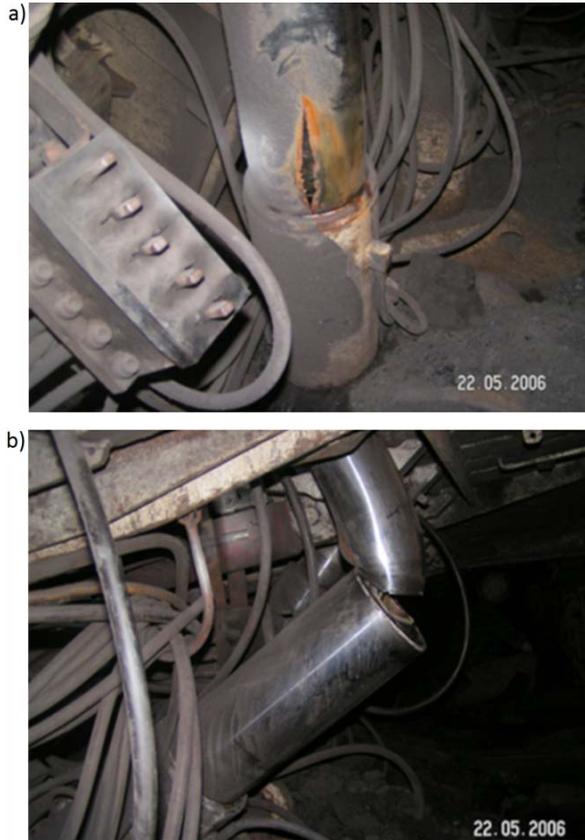


Figure 3. Damage to hydraulic legs of powered roof support caused by dynamic phenomena; a) - torn, b) - broken (Prusek and Masny 2015).

#### 4. PROTECTING POWERED SUPPORT FROM CONSEQUENCES OF ROCK BURSTS

A lot of actions have been taken to limit consequences of damage to powered support or of stability loss in mine workings. It means preventing rock bursts with periodic destressing in zones where they concentrate or inducing rock mass tremors. The most often applied methods are: watering a seam, destressing drilling, loosening blasting, torpedo blasting, directed hydrofracturing of rocks, directed blasting fracturing, and destressing a seam through mining adjacent seams (Brauner 1994; Junker et al. 2006). Moreover, there are also various types of underground tests (Li et al. 2014; Turek et al. 2015) and laboratory tests (Player et al. 2008) aimed at

assessing the influence of increased load induced by seismic phenomena on the support and stability of mine workings.

According to Polish legislation (Ordinance of the Minister of Economy of 2002) a powered roof support which is to work in longwalls driven in areas of rock mass tremors has to be flexible to absorb dynamic load. That is why, for many years, the Central Mining Institute has been conducting research into assessing the flexibility of powered roof supports (Prusek et al. 2005; Rajwa et al. 2009; Stoiński 2015; Stoiński et al. 2015). By “support flexibility”, according to GIG’s methodology, we mean the property of a powered roof support which enables it to absorb dynamic load safely, without exceeding values of its safety factor coefficient. The Central Mining Institute’s method assumes that hydraulic legs and flow rate of the hydraulic system are the key elements making a given support flexible. The calculated minimal height of liquid column in the under piston space of a hydraulic leg (PT) and the determined flow rate of the system (together with a yielding valve) allows determination of the operation height range of a powered support, at which it is considered to be flexible under dynamic load (coefficient  $n_{tz}$ ). In the calculations the value of maximum load on a leg and its nominal load are compared, in accordance with the following condition:

$$F_{max} < k \cdot F_N \quad (1)$$

where:

$F_{max}$  – value of maximum expected load on leg, considering rock mass tremor energy, N

$F_N$  - leg nominal load, N.

$k$  – safety factor coefficient for hydraulic leg determined in laboratory (usually 1.5 or 2.0).

The value of maximum forecast load of a leg  $F_{max}$  is determined analytically with the course of load versus time  $f(t)$ , based on a model of one degree of freedom, and the equation (Stoiński et al. 2015):

$$f(t) = \frac{1}{\cos \alpha} \{ F_w + F_d [1 + k_d e^{-\delta t} - \sin(\omega t - \varphi)] \} \quad (2)$$

where:

$F_w$  – leg setting load, N,

$F_d$  – dynamic force of load,  $F_d = n_{tz} \cdot F_r - F_w$ , N,

$F_r$  – yield load, N,

$n_{tz}$  – load coefficient,

$k_d$  – computational coefficient,

$\omega$  – angular velocity, rad/s<sup>-1</sup>,

$\varphi$  – shift angle of the force with respect to input function, rad,

$\alpha$  – yaw angle of the leg from the normal to the support base, rad,

$\delta$  – equivalent damping resulting from hydraulic valves and rock displacement resistance,  $s^{-1}$ ,  
 $t$  – time, s.

Flexibility of a section is also associated with flow rate of the hydraulic system, applied to limit pressure in the under piston space of a leg. It is important the configured hydraulic system securing the under piston space of a hydraulic leg does not limit flow  $Q_u$  in selected yielding valves. The hydraulic system ought to have both optimised liquid streams geometry, and determined characteristics of flow of given elements in the whole system. Flow of liquid in the leg hydraulic system can be assessed in laboratory tests (Stoiński 2015) or by using numerical modelling based on ANSYS CFX software (Fig. 4) (Doległo et al. 2009). Figure 4 presents a sample result assessing flow of liquid in the hydraulic system securing the space under piston.

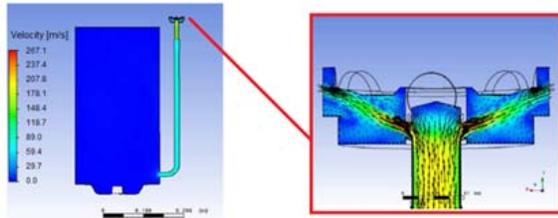


Figure 4. Assessment of flow of liquid in leg hydraulic system performed with ANSYS CFX software (Doległo et al. 2009).

The factors which in practice are most often considered while assessing flexibility of the support are: value of load coefficient  $n_{tz}$ , flow rate of the yielding valve of a hydraulic leg  $Q$  and ratio of setting load and yield load  $n_0$ . An example of the assessment of powered support flexibility at heights between 1.8 and 3.4 m, applied in conditions where rock mass tremors occur are presented in Figure 5.

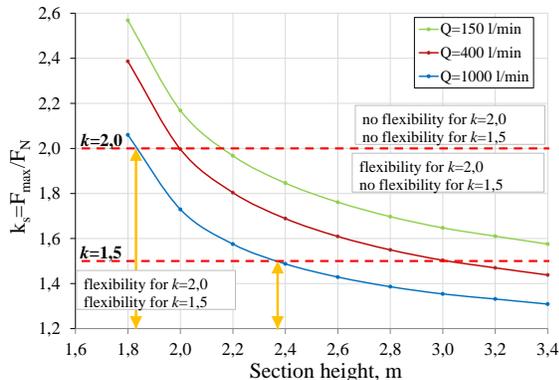


Figure 5. Change in leg overload coefficient  $k_s$  depending on operation height of shield and flow rate of yielding valve  $Q$  (assumptions: coefficient  $n_0=0.66$ ; values of load coefficient  $n_{tz}=1.2$ ) (Prusek 2015).

Proper selection of flow rate of yielding valves  $Q$  has a significant influence on support shield flexibility. In Figure 5 it can be observed that an increase in flow rate of the yielding valve results in an increase in the range of height of the support at which it is flexible for the calculated (determined) dynamic load. For the yielding valve of flow rate  $Q=1000$  l/min, the analysed shield support, with the legs tested in laboratory conditions at safety factor coefficient  $k=2.0$ , meets the flexibility condition in the height range of 1.85–3.30 m, while for coefficient  $k=1.5$ , it does in the height range of 2.35–3.30 m.

## 5. SUMMARY

Statistical data presented in the article and analyses concerning the consequences of observed rock bursts and decompression events prove that they are phenomena posing a threat to personnel safety, and have a significant influence on the continuity of production. Recent years' practice showed that by applying a proper set of rules and safety measures it is possible to limit the above-mentioned threats significantly. According to the GIG's method, to improve flexibility of a powered roof support, presented in the article, it is believed that sufficiently strong construction of the leg is significant. The construction ought to ensure its further operating when pressure in its under piston space increases to the double value of nominal pressure (safety factor coefficient  $k=2.0$ ). Then, the flow of the liquid stream is optimized and a yielding valve of flow rate resulting from the forecast dynamic load is selected. Moreover, it is favourable, from the point of view of the ability to absorb greater dynamic load by a powered roof support, to apply possibly the highest values of setting load (value of coefficient  $n_0$  increases). It is also possible to try to lower values of yield load. However, such a decision ought to be preceded with other analyses concerning proper co-operation between the powered roof support and the rock mass to stabilise the roof of a longwall.

## 6. ACKNOWLEDGEMENTS

Article presents a brief part of work carried out by the Central Mining Institute within the frame of research under the project: I<sup>2</sup>M Innovative Technologies and Concepts for the Intelligent Deep Mine of the Future. The project was implemented under The Seventh Framework Programme of the European Union.

## 7. REFERENCES

Biliński A. (2005): Metoda doboru obudowy ścianowych wyrobisk wybierkowych i chodnikowych do warunków pola eksploatacyjnego (Method of

selecting support for conditions in mining panel). CMG Komag, Gliwice.

Brauner, G. (1994): Rockbursts in coal mines and their prevention. Balkema, Rotterdam, str. 144.

Cybulski K., Malich B. (2015): Zagrożenie pyłowe.: Raport roczny o stanie podstawowych zagrożeń naturalnych i technicznych w górnictwie węgla kamiennego 2014 (Dust hazard: Yearly report on basic natural and technical hazards in hard coal mining in 2014). Praca zbiorowa pod kierunkiem J. Kabiesza. pp. 41-60.

Doległo L., Gil J., Stoiński K. (2009): Analityczna ocena wydajności objętościowej układu hydraulicznego stojaka zmechanizowanej obudowy ścianowej (Analytical assessment of volumetric efficiency of hydraulic system of a powered roof support leg ). *Maszyny Górnicze* 4/2009 pp 9-18

Junker M. et al. (2006): Gebirgsbeherrschung von Flözstrecken. Verlag Glückauf, Essen.

Li L., P. Hagan P., Saydam S. (2014): A review of ground support systems performance subjected to dynamic loading. Conference Paper, DOI: 10.1201/b16955-183 Conference: EUROCK 2014, At Vigo, Spain, Volume: Rock Mechanics and Rock Engineering: structures on and in rock masses.

Mutke G. (2008): Stability of the underground mine workings in the near-field zone of seismic events. In : 21st World Mining Congress 2008 – New Challenges and Vision for Mining. Underground Mine Environment. 7-12 September 2008 – Poland – Cracow. University of Science & Technology (AGH), pp. 89-97.

Patyńska R. (2015): Zagrożenie tąpnięciami.: Raport roczny o stanie podstawowych zagrożeń naturalnych i technicznych w górnictwie węgla kamiennego 2014 (Rock burst hazard: Yearly report on basic natural and technical hazards in hard coal mining in 2014). Praca zbiorowa pod kierunkiem J. Kabiesza. pp. 96-107.

Player, J. R., E. Villaescusa, and A. G. Thompson. 2008. "An examination of dynamic test facilities." In 2008 Australian Mining Technology Conference, Sep 16, 2008, Twin Waters Queensland: The Australasian Institute of Mining and Metallurgy.

Prusek S. (2015): Stateczność wyrobiska ścianowego podczas eksploatacji pokładów węgla kamiennego z zawalem skał stropowych (Stability of longwall during hard coal mining operations with roof caving). Książka w druku.

Prusek S., Masny W. (2015): Analysis of damage to underground workings and their support caused by dynamic phenomena. *Journal of Mining Science*, Vol. 51, No. 1, pp. 63–72.

Prusek S., Rajwa S., Stoiński K. (2005): Kriterien zur Abschätzung des Risikos von

Strebschaden. *Glückauf-Forschungshefte* 2005, no 3, pp. 92-95

Rajwa S., Masny W., Prusek S. (2009): Powered Support in Conditions of Rock Mass Tremor Occurrence in the Polish Mining Industry. *Aachen International Mining Symposia, 5<sup>th</sup> International Symposium – High Performance Mining, RWTH Aachen*, pp. 359-373.

Rozporządzenie Ministra Gospodarki z dnia 28 czerwca 2002 r. Dz. U. Nr 139 poz. 1169 z późniejszymi zmianami, w sprawie bezpieczeństwa i higieny pracy, prowadzenia ruchu oraz specjalistycznego zabezpieczenia przeciwpożarowego w podziemnych zakładach górniczych (Ordinance of the Minister of Economy of 28 June 2002 on occupational health and safety, management of operation and specialist fire protection in mining facilities extracting mineral resources).

Rozporządzenie Ministra Spraw Wewnętrznych i Administracji z dnia 14 czerwca 2002 r. Dz. U. Nr 94, poz. 841 z późniejszymi zmianami, w sprawie zagrożeń naturalnych w zakładach górniczych (Ordinance of the Minister of Internal Affairs and Administration of 14 June 2002 on natural risks in mining plants)

Stec K. (2015): Zagrożenie sejsmiczne. W: Raport roczny o stanie podstawowych zagrożeń naturalnych i technicznych w górnictwie węgla kamiennego 2014. Praca zbiorowa pod kierunkiem J. Kabiesza. Główny Instytut Górnictwa (Seismic hazard: Yearly report on basic natural and technical hazards in hard coal mining in 2014), Katowice, pp. 82-95.

Stoiński K. (2015): Doświadczenia i obserwacje własne z wpływu oceny „upodatkowania” zmechanizowanych obudów ścianowych na ich optymalizację konstrukcji (Experience and own observations of influence of assessing “flexibility” of shield supports on optimising their construction). IX Międzynarodowa Konferencja Techniki Urabiania organizowana w ramach III Polskiego Kongresu Górniczego Kraków-Krynica.

Stoiński K., Prusek S., Rajwa S. (2015): Dobór przepływów w układzie zabezpieczającym stojak zmechanizowanej obudowy ścianowej – opis przypadku (Flow selection in the system securing a shield support leg. Case study). XXIII. Międzynarodowa konferencja naukowo-techniczna TEMAG 2015. Ustroń, 21-23.10.2015 r.

Turek M., Prusek S., Masny W. (2015): Obudowa podporowo-kotwowa w kopalniach węgla kamiennego (Steel arch support with roof bolts hard coal mines). Monografia, wydaw. GIG.