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THE CONSEQUENCES OF ROCK BURST HAZARD FOR SILESIAN COMPANIES IN POLAND

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ABSTRACT

Seismic and rock burst hazards still currently appear to be important in most hard coal mines in Poland. Recently, there has been a significant increase in seismic activity in the Silesian rock mass, in comparison to previous years. In the period 2001–2010, hard coal mines experienced 33 rock bursts. The causes of rock burst occurrences are here presented, based on an analysis of the rock bursts that occurred in Polish hard coal mines. The scale of the rock burst hazard has been characterized with respect to the mining and geological conditions of the existing exploitation. The most essential of the factors influencing the status of rock burst hazard is considered to be the depth of the interval, ranging from 550 m to 1150 m.

The basic factors that cause rock burst to occur are as follows: seismogenic strata, edges and remnants, goafs, faults, pillars and excessive panelling. The consequences of rock bursts are damaged and/or destroyed roadways.

On this basis, the areas (ranges) of safe zones were selected as being those safe from rock burst hazard in roadways, according to the assessment conducted to establish different degrees of the risk.

KEYWORDS: rock burst hazard, parameters of rock bursts, consequences of rock bursts

1. INTRODUCTION

The output of coal in Poland has been continuously decreasing since the year 1978 (Fig. 1). Coal mining output in the years 2001–2010 reduced from 102.8 mln tonnes to 76.1 mln tonnes.

The existing methods of hard coal mining in Poland have been in use since the 1960s and 1970s. The methods and technology for reducing rock burst hazards have made great strides, and the number of rock bursts in hard coal mines decreased drastically from 39 in 1972 to 2–5 in recent years. Between 2001 and 2010, the total number of recorded rock bursts was 33 (Fig. 2; Patyńska, 1989–2010).

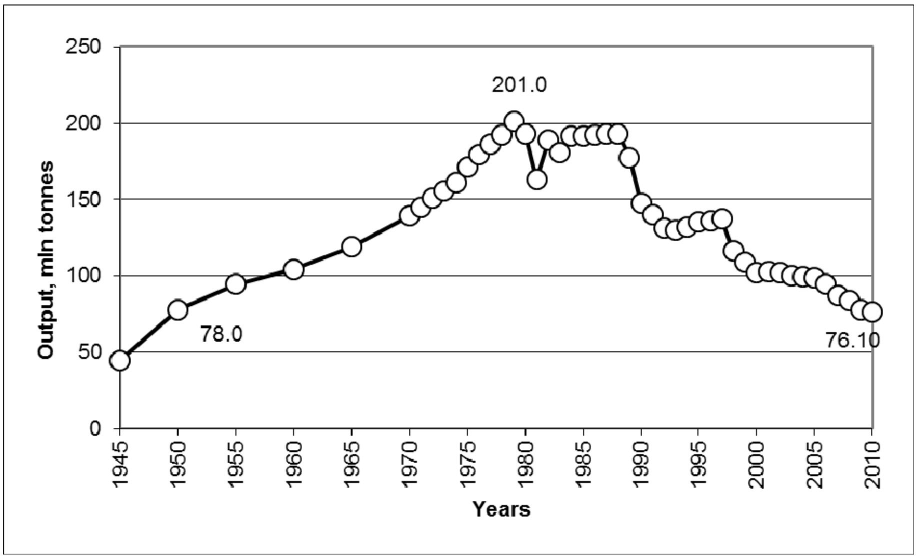

Fig. 1 Hard coal output in the Upper Silesian Coal Basin mines in 1945–2010.

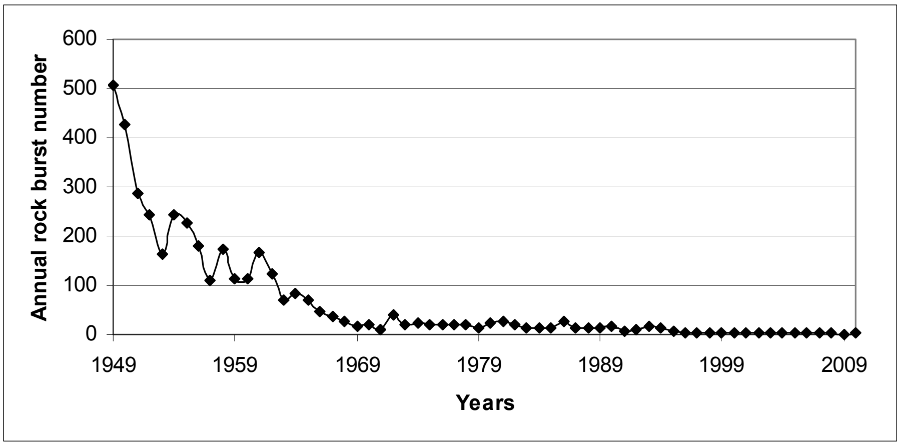

Fig. 2 Number of rock bursts in the Upper Silesian Coal Basin (USCB) hard coal mines in 1949– 2010.

In addition to mining and geological conditions, rock burst occurrence was also influenced by a lack of the advanced technical equipment required for the mining systems, and an inadequate level of knowledge about the methods for predicting and combating the state leading to rock burst hazard.

The decrease of rock bursts in recent years has been achieved due to the development of source and hazard condition evaluation, which has enabled a proper design for the operation of coal seams located in the rock burst hazard areas, as well as the development of a method for preventing rock burst, especially the method of directional hydraulic fracturing of rocks (UHS) and directed blasting fracturing (USS) (Dubiński and Konopko, 2000). The reduction of production volume in USCB is also not without meaning.

2. THE MINING AND GEOLOGICAL CONDITIONS RELATED TO THE SCALE OF ROCK BURST HAZARD

Seismic and rock burst hazards occur in the majority of Polish hard coal mines. These are influenced by a number of factors, of which the most important are the following (Dubiński and Konopko, 2000; Holub et al., 2012; Konopko, 1994; Konopko and Patyńska, 2008; Procházka et al., 2010):

- depth of mining operations and the resulting rock mass pressure;
- thick monolithic sandstone layers with a high uniaxial compressive strength occurring in the roof (60–150 MPa);
- evidence of past mining in the form of remnants, pillars and coal seam edges;
- primary and secondary tectonic settings of the deposit (faults, cleavage);
- mining and coal seam remnants;
- natural proneness of coal to rock bursts (bumpiness of the roof–coal seam–floor system).

According to statistical analysis of the locations and conditions of the rock bursts that occurred in the years 2001–2010, those events were accompanied by energy tremors in the mine ranging from 10^5 J to 10^8 J. The unit expenditure of energy (EE) tended to grow continuously (Fig. 3).

An increase in seismicity, estimated as the energy radiated per 1 tonne of extracted coal, has been recorded over the past 10 years. The average value of the seismicity during that period was 25.8 J/tonne; the average number of tremors was 1142 and showed an upward trend, especially after 2004. In the year 2009, EE was 30.5 J/tonne and the increase in the year 2010 almost doubled to 58.4 J/tonne (Fig. 3).

Table 1 shows the statistical data that confirm the high seismicity of the Upper Silesian Coal Basin rock masses. The above-mentioned seismicity trend is distinctly visible in the higher range of energy (10^7–10^9 J). This occurs due to the strong connection with rock burst occurrence.

The seismic characterization of USCB is based upon several years worth of data from the Upper Silesian Regional Seismic Network (GRSS). Central Mining Institute (CMI) archives have shown that there are two types of seismic activity: mining and mining-tectonic (Stec, 2007). The first of these is directly related to the involvement of mining operations, and therefore mainly occurs in the vicinity of active mine workings. The second type is a result of the interaction between mining and tectonic factors. Most of these earthquakes are located in the area of tectonic faults and feature significantly higher seismic energy.

Rock burst occurrence generates both effects on mine workings and casualties. This is very undesirable from a practical point of view. The measures taken to prevent hazards from mine tremors and rock burst occurrence are designed to reduce these dangerous consequences of rock burst and seismic events. Table 2 shows the number of rock bursts and the resulting casualties, as well as the hard coal output (including the output from the coal seams effected by

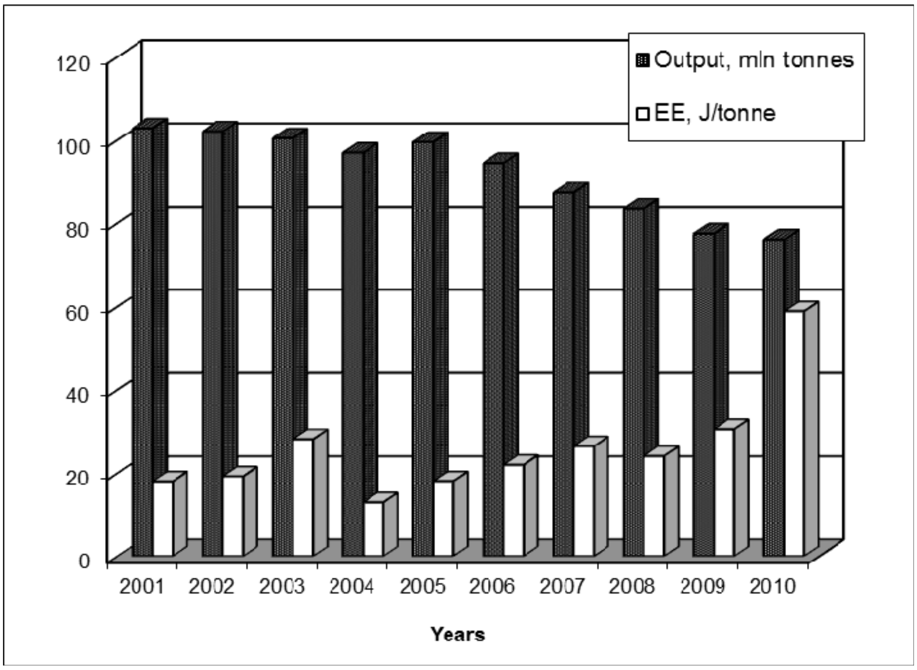

Fig. 3 Hard coal output and unit expenditure of energy (EE) in the Upper Silesian Coal Basin mines in 2001–2010.

Table 1 Seismicity of the Upper Silesian Coal Basin rock masses in the years 2001–2010 (Patyńska, 1992–2011).

Year	Number of tremors (n_w) of energy E (J)					
	10^5	10^6	10^7	10^8	10^9	Total
2001	927	192	18	0	0	1137
2002	1135	171	18	0	0	1324
2003	1302	193	28	1	0	1524
2004	845	112	16	0	0	973
2005	1256	180	14	1	0	1451
2006	976	168	26	2	0	1172
2007	833	99	5	1	1	939
2008	787	114	15	1	0	917
2009	666	90	14	2	0	772
2010	1035	157	12	1	1	1206

Table 2 Coal output, high energy tremors and the effects of rock bursts in Upper Silesian Coal Basin mines in the years 2001–2010.

Year	Total output	Output from coal seams under rock burst hazard risk		Incidence rate (casualties/ output)	Number of rock bursts	Rock bursts: related casualties		Effects on excavations	
	mln tonnes		% of total			lethal	non-lethal (severe and light)	destroyed and collapsed, m	damaged, m
2001	102.80	37.6	36.6	0.20	4	2	19	0	668
2002	102.10	42.2	41.3	0.20	4	3	17	0	590
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[1]	41.2[1]	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[1]	49.43[1]	0.11	3	0	10	0	530
2008	83.60	41.9	50.12	0.31	5	0	26	–	710
2009	77.5	34.3	43.8	0.06	1	0	5	–	101
2010	76.1	35.8	47.04	0.18	2	2	12	30	87

Notes: [1] - approximate data

Table 3 Rock bursts in Upper Silesian Coal Basin mines in the years 1989–2010.

Parameters of rock bursts	In the period 1989–2010	In the period 2001–2010
Number of rock bursts	132	33
Tremor energy level, J	average $1.67 \cdot 10^7$ min. $3.11 \cdot 10^3$ max $5.00 \cdot 10^8$	average $2.94 \cdot 10^7$ min. $2.00 \cdot 10^5$ max $2.00 \cdot 10^8$
Depth of rock bursts, m	average 760.24 min. 400.00 max 1150.00	average 839.45 min. 550.00 max 1150.00

rock burst hazard), and the number of mine tremors and the scale of the damage caused by rock bursts. The number of casualties, and the effects in terms of the damage to excavations during the period under discussion, remain at an approximately similar level. The incidence rate reached an average value of 0.18.

2.1. STATISTICS FOR ROCK BURSTS OCCURRING IN THE MINES OF THE UPPER SILESIAN COAL BASIN

One of the criteria for the distribution of the geological structure of the rock mass is the stratigraphy of USCB: the age of deposition of the layers of rock. Stratigraphic division also applies to the layers of rock and the seams of coal located within them. So far, the production of coal in Poland has been carried out in stratigraphic groups 200–800.

The statistic analysis of rock bursts occurring in the period 1970–2010, as presented in the *Data Bank of Rock Bursts* (Patyńska, 1989–2010), show that for a total number of 497 rock bursts in the USCB mines, as many as 464 cases occurred in the seams of group 500. Within the same time period, only 11 rock bursts were noted in the seams of group 400 and only six in those of group 600.

In the period 1989–2010, 132 rock bursts were recorded for Silesian Companies in Poland. There were 117 rock bursts in the seams of group 500. In the same time period, only eight rock bursts were noted in group 400 seams, three in the seams of group 600, and four in the seams of group 700. The depth of deposition of seams in all group seams was taken to be from 400 m to 1150 m (average depth 760 m).

In the last ten years (in the period 2001–2010), there were 33 rock bursts at a depth of 550–1150 m (average depth 839.45 m) (Table 3). There were 22 rock bursts in group 500 seams. In the same period, six rock bursts were noted in group 400 seams, one in group 600 seams and four group 700 seams.

The data show that both the exploitation and depth of rock bursts are constantly increasing.

The depth of the group 500 coal seam, in which as many as 22 rock bursts (in the period 2001–2010) have occurred, extends from 550 m to 970 m. It is not expected that this depth would be the most dangerous. The number of rock bursts should rather be related, for example, to the number of coalfaces or to the output related to the depth of the intervals. A depth of 777 m could be expected to be associated with the highest output and therefore with the highest number of rock bursts. It is important to note that the average depth of mining in the Upper Silesian Coal Basin mines is currently 702 m. This can easily account for rock bursts occurring at close to this depth, near to where coalfaces are being mined most heavily.

According to statistical analysis, there were 132 rock bursts in hard coal mines in the period 1989–2010 (Patyńska, 1989–2010). In most cases, the effects of these events were evident in the workings associated with the group 500 seams. The thickness of these seams was estimated to be in the range of 1.3 to 14.40 m. The characteristic height of seam workings where the rock bursts occurred was in the range of 1.3 to 4.0 m, with a dip angle in the range of 2^0 to 21^0; only in the case group of 620 in 'ZWSM Jadwiga', was the dip angle larger, in the range 20^0 to 31^0. The average thickness of seismogenic strata was estimated as 20 m, with the average average distance estimated as 40 m.

Some rock bursts were located in local fault zones (primary and secondary tectonic mass with faults reaching several metres). The average fault size was estimated as 8 m. The size parameters were comparable (Table 4).

The characteristics of rock burst occurrence, based upon the available descriptive material and mining maps, allowed the location of the workings (longwalls or headings) to be systematized in relation to the closest fault (Patyńska, 2004, 2008). Thus, an unequivocal assessment based on counting the fronts as hanging or foot walls can be determined according to the deposition of fault planes in their immediate surroundings. There were 75 cases of rock burst noted where the front of the mining works was located in the foot wall, and 57 rock bursts where the front was located in the hanging wall. In other cases, rock bursts were not related to any faults; the effects of three rock bursts were noted in the longwalls where the front of the longwall field was located in the surroundings of, but further along, the fault planes.

Statistical analysis showed that rock bursts in the period 1989–2010 were accompanied by rock mass

Table 4 Parameters of rock bursts in the Upper Silesian Coal Basin mines in the years 1989–2010.

No.	Coal mines/date	Coal seam group	The thickness of the deck/ height of the workings, m	Tremor energy level, J	Depth, m
1.	"Rydułtowy-Anna", 21.10.2010	$713/_{1-2}+712/_{1-2}$	3.0–3.6/3.0–3.6	$7 \cdot 10^5$	1140
2.	"Rydułtowy-Anna", 24.03.2010	$713/_{1-2}+712/_{1-2}$	3.0–3.9/3.4	$1.9 \cdot 10^6$	1140
3.	"Bielszowice", 5.10.2009	405/2	7.2–8.2/3.0	$3 \cdot 10^7$	1050
4.	"Staszic", 23.02.2008	501	4–6.3/3.2	$2 \cdot 10^7$	930
5.	"Wujek", 16.04.2008	502	2.6–8.5/3.3	$9 \cdot 10^7$	630
6.	"Bielszowice", 24.07.2008	510	6.9–8.8/3.2	$8 \cdot 10^5$	840
7.	"Mysłowice-Wesoła", 11.09.2008	510	4/3.5	$8 \cdot 10^5$	550
8.	"Halemba-Wirek", 21.11.2008	504	2/2	$1 \cdot 10^7$	600
9.	"Zofiówka", 10.04.2007	409/3	1.95–2.6/2.4	$1 \cdot 10^6$	966
10.	"Jas-Mos", 25.04.2007	510/1	2.4–3.8/3.1	$2 \cdot 10^5$	970
11.	"Pokój", 19.07.2007	502	4.2–6.4/3.3	$8 \cdot 10^7$	730
12.	"Halemba", 22.02.2006	506	1.4–2.5/ 1.7	$2 \cdot 10^8$	910
13.	"Rydułtowy Anna", 13.05.2006	703/1	1.2–2.3/1.6	$1 \cdot 10^8$	1050
14.	"Pokój", 27.07.2006	502	5.6–6.4/3.3	$9 \cdot 10^7$	970
15.	"Rydułtowy-Anna", 19.12.2006	703/1	1.8–2.1/ 1.6	$9 \cdot 10^7$	1050
16.	"Bielszowice", 27.01.2005	502	2.2–5.5/3.1	$1 \cdot 10^7$	890
17.	"Bobrek-Centrum", 22.08.2005	510 w.g.	9.0–9.7/2.9	$2 \cdot 10^6$	690
18.	"Pokój", 25.11.2005	418	2.0–3.0/3.6	$1 \cdot 10^7$	745
19.	"Halemba", 22.01.2004	415/1	3.5–6.0/2.9	$9 \cdot 10^7$	770
20.	"Halemba", 11.02.2004	415/1	3.5–6.0/2.9	$9 \cdot 10^5$	770
21.	"Polska-Wirek", 20.09.2004	502	6.0/3.3	$3 \cdot 10^7$	711
22.	"Katowice-Kleofas", 4.03.2003	510	6.2/3.4	$2 \cdot 10^7$	620
23.	"Wesoła", 24.03.2003	501B	3.5–3.75/3.5	$2 \cdot 10^6$	760
24.	"Wujek", 18.08.2003	510	4.3–5.2/2.5	$2 \cdot 10^6$	750
25.	"Wujek", 10.09.2003	510	4.3–5.2/2.5	$4 \cdot 10^6$	760
26.	"Sośnica", 8.01.2002	504	7.9–12/3.0	$6 \cdot 10^5$	700
27.	"Śląsk", 25.01.2002	502/J	5.8–10.4/3.0	$6 \cdot 10^7$	910
28.	"Wesoła", 9.08.2002	501	3.3–4.85/3.5	$4 \cdot 10^6$	760
29.	"Bielszowice", 7.09.2002	405/2	7.2–8.0/3.0	$5 \cdot 10^5$	1150
30.	"Anna", 5.02.2001	630/2	2.9/2.9	$6.6 \cdot 10^5$	930
31.	"Katowice-Kleofas", 15.02.2001	510/II	5.9–7.2/2.0	$1 \cdot 10^7$	660
32.	"ZG Bytom II", 26.06.2001	510	7.4/3.2	$2 \cdot 10^5$	930
33.	"Wesoła", 14.09.2001	501	4.0/4.0	$8 \cdot 10^6$	820

quakes of energy 10^3–10^8 J. In the period 2001–2010, rock bursts were characterized by tremors of energy 10^5–10^8 J. The average energy level of tremors constantly increased from 1.67×10^7 J (in the period 1989–2010) to 2.94×10^7 J (in the period 2001–2010).

In comparison with a similar report based on data from the years 1977–1982, the risk of occurrence of rock bursts with low and average energies has increased by an order of two to three (Konopko and Patyńska, 2008). However, it has remained unchanged at energy $E \geq 10^6$ J. These data confirm the theory that at higher mining depths (currently averaging 702 m, and 486 m in 1977) and with the resulting higher rock mass effort (stress concentration), medium-energy mine tremors can cause the same level of occurrence of dynamic events.

During recent years, the scale for the number of rock burst hazards has been relative to the data presented in Table 5.

2.2. CONSEQUENCES OF ROCK BURSTS THAT OCCURRED IN LONGWALL COALFACES AND HEADINGS OF THE UPPER SILESIAN COAL BASIN MINES IN 2001–2010

The locations of rock burst effects, based on the type of excavation and its position with respect to the abutment stress zone, are specified in Table 6. Such a subdivision is dictated by the different values of the pressure (rock efforts) around the excavations and their variable structures. Out of 33 cases, 27 rock bursts in the excavations and gate roads were influenced by abutment stress. The remaining six

Table 6 Consequences of rock bursts that occurred in longwall coalfaces and headings of the Upper Silesian Coal Basin mines in the years 2001–2010.

Year	Number of rock bursts	Headings off the active face line	Longwall	Roadways	Coalfaces along a gateroad
2001	4	2	–	2	–
2002	4	–	–	4	–
2003	4	1	–	1	2
2004	3	1	–	–	2
2005	3	–	–	–	3
2006	4	–	–	1	3
2007	3	–	–	3	–
2008	5	1	–	3	1
2009	1	–	–	1	–
2010	2	1	-	-	1
Total	33	6	-	15	12

cases occurred in the passageways situated behind the stress zones induced by current mining operations.

3. ANALYSIS OF THE RANGE OF THE EFFECTS OF ROCK BURST IN THE VICINITY OF THE LONGWALL FOREFIELD

Analysis of rock bursts in terms of areas affected by damaged and/or destroyed headings, particularly in the field service environment, is essential in rock burst prevention. Proper assessment of the risks posed by rock bursts in selecting the length of the expected impact zone affects its accuracy and decisions on prevention of rock burst hazards.

Since CMI possesses a wide range of source material (the Rock Bursts Data Bank of USCB; Patyńska, 1989–2010) relating to existing rock bursts, including details of geological, mechanical and technical characteristics, those data were reviewed and lengths were selected based on analysis of the prevalence of various ranges of rock burst effects and their distance from the frontwall. Of particular dealt relevance was the incidence of various ranges of damage and/or destruction headings in the vicinity of frontwalls. The purpose of this study was to determine the extent of the safe zone for different degrees of recorded risk.

3.1. THE RANGE OF THE EFFECTS OF ROCK BURSTS IN THE ENVIRONMENTAL FRONT LONGWALL

A total of 88 specific cases from the rock bursts that occurred in the years 1989–2010 in USCB were selected for analysis, including the effects on the longwall in the workspace and/or its surroundings, and with excavations varying from 0 to 300 m. Comparing the ranges of the energy shocks, which caused the rock burst, illustrates the scale of the analysed event.

The Data Bank of Rock Bursts was used to determine that the scale of effects reported here refers to seismic shocks caused by rock bursts of 104–108 J. The rock bursts were noted to be associated with an exploitation depth in the range of 410–1150 m (average 768 m), in locations surrounded by the front of the longwall with a length of 45 to 400 m (average length of the front was about 163 m).

In order to determine any changes in the prevalence of various ranges of rock burst effects, we calculated the incidence of absolute, relative and cumulative ranges, grouped in class intervals at increments of 10 m, 25 m and 50 m.

The distributions of different ranges of effects and the decrease in frequency clearly indicated that variations are dependent on class frequency and interval length. The trend of these changes in terms of logarithmic curves and equations indicated differences in the slope distributions. The best-fit curve was for a range of effects related to intervals that are 25 m long (R2 = 0.98), and the most adequate was related to the distribution of the effects of grouping rock burst ranges in increments of 10 m (Fig. 4a).

The distribution shown in Fig. 4a–c in each column differentiates the frequency distribution of relative frequency (percentage); the effects of different ranges are related to the same data set, depending on the adopted class compartment. The curve trend of the frequency ranges clearly indicates that the rate of increase in the long range effects of the individual frequency ranges is decreasing. The frequency distribution in Figure 4c, however, is not able to determine the quality of how those ranges are decreasing. Analysis of density ranges with class intervals of 25 m shows (Fig. 4b) that the decrease in the frequency of the effects of impacts is at its greatest between 0–25 and 26–50, and remains at a similar level in the range of 26–125 m. Class compartments in ranges of 10 m (Fig. 4a) directly indicate that a value below a 10 m frequency range records rockburst effects at a level of about 22 %. In the range of 10–140 m, total frequency ranges records effects at a level of about 60 %. On this basis, it should be noted that the effects of rock burst hazards occur most frequently

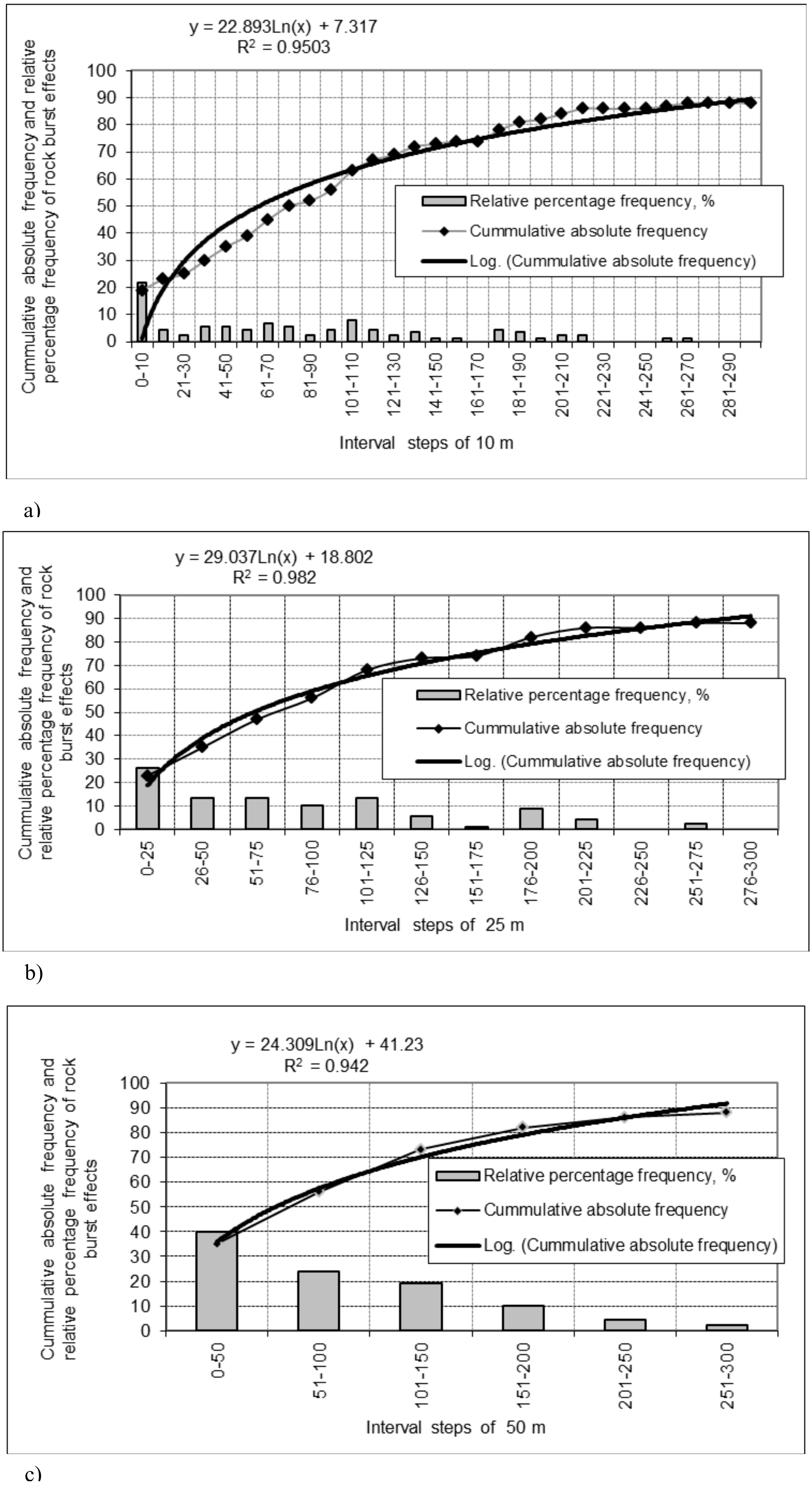

Fig. 4 Frequency range of the effects of rock bursts at interval lengths of a) 10 m; b) 25 m; c) 50 m.

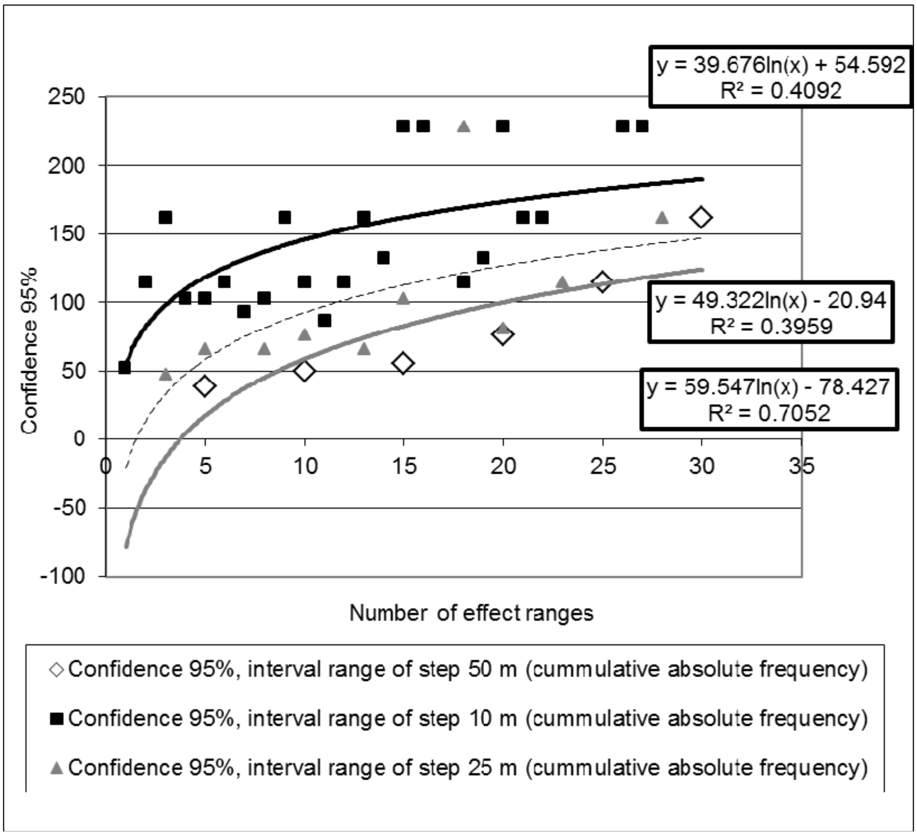

Fig. 5 Confidence level of effect ranges of rock bursts.

at lengths of up to 140 m, both in the top and bottom gates. The collection of ranges that they represent is about 82 % of the ranges analysed for all effects.

3.2. *CONFIDENCE IN THE FREQUENCY OF THE RANGES OF EFFECTS OF ROCK BURSTS IN THE FRONTWALL VICINITY*

In order to authenticate the analysis in Figure 5, we examined the distribution of curves for the confidence intervals of all of the analysed frequency ranges relating to absolute effects, ranging from 0 m to 300 m. The highest value for the confidence ranges of the frequency distributions showed an interval class of 10 m, for which the trend curve yielded the maximum confidence for the entire set of ranges relating to the analysed effects.

Referring to the adjusted R2 values of the logarithmic curves for the individual confidence distributions, we took this value as a basis for analysing the range of effects at a step of 50m, with the best-fit matching the logarithmic curve of 95 %.

On this basis, it was clear that defining the range of effects, and thus determining the length of rock burst danger zones, should identify the selected excavations as being particularly vulnerable, at least to a distance of about 220 m. That value coincides with the maximum confidence level (95 %) of the set of effects of absolute rock burst frequency ranges analysed in increments of 10 m.

The best-fit logarithmic curve for ranges of rock bursts effects was obtained for frequency steps of 50 m (Fig. 4c) so it must be assumed that the greatest expected impact of rock bursts are in the ranges between 0 and 150 m.

Hence the requirement that frontwall sidewalks should be created at the third risk level would be met if rock burst is prevented to at least 150 m.

The longwall sections of the top gates, from above 150 m to 220 m, can be defined as zones where there is a lower degree of rock burst hazard. Other sections of the excavation that are above 220 m long can be classified as being the least vulnerable to the effects of rock bursts.

4. CONCLUSIONS

Despite a smaller number of rock bursts and their consequences having been recorded over the past 10 years, we observed an upward trend in rockburst hazards, especially with regard to the seismicity of the rock mass. This is probably associated with the amount of output and concentration of work at individual longwall panels, as well as with the depth of the excavation.The synthesis of the conditions under which rock burst occurred in hard coal mines in the years 1989–2010 can be summarized into the following statements and conclusions:

- The hard coal output declined from 177.6 mln tonnes in 1989 to 76.1 mln tonnes in 2010. The average mining depth increased from about 524 m to 702 m during that same period.

- In the period 1989–2010, 132 rock bursts were recorded for Silesian Companies in Poland. There was 117 rock bursts in group 500 seams. In the same time period, only eight rock bursts were noted in group 400 seams, three in group 600 seams, and four in group 700 seams. The depth of deposition for all group seams was from 400 m to 1150 m (average depth 760 m).
- The statistical analysis of rock bursts in the period 1989–2010 showed that they were accompanied by rock mass quakes of energy 10^3–10^8 J. The mining operations were inducing mine tremors of energy levels up to 10^9 J. The average energy of the tremors was constantly increasing from 1.67×10^7 J (in the period 1989–2010) to 2.94×10^7 J (in the period 2001–2010).

In order to determine the consequences of rock bursts, 132 were analysed relating to the years 1987–2010, of which 95 cases were selected based solely to the effects in the surroundings of the longwalls. Table 4 summarizes the number of rock bursts the effects of which were felt in the area of the longwalls, main gates and bottom gates and working spaces, in the form of damage to the walls and/or destruction of the excavations.

Analysis of the set of ranges of effects of rock bursts showed them to be limited to ranges of lengths from 0 m to 265 m which, after rejecting outliers and extreme ranges, referred to only 88 cases.

In order to determine changes in the prevalence of the various ranges of effects, we calculated the frequency of absolute, relative and cumulative effects, grouped in class intervals in increments of 10 m, 25 m and 50 m.

The frequency ranges of effects clearly showed their differences, depending on the grade and length of the interval frequency ranges (Figs. 4a–c).

The trend for logarithmic curves and equations in Figure 5 indicates the diversity of different confidence distributions for the long range effects; the most reliable set is the distribution range in increments of 50 m, based on the confidence curve.

On this basis, the areas (roadways) deemed to be safe zones (i.e. outside the relevant risk zone for rock burst hazards) were assessed for different degrees of risk, as follows:

- Roadways created in areas of risk level I, II or III in relation to rock burst hazards should be covered by rock burst prevention measures to at least 150 m;
- Another zone comprises roadways above 150 m to 220 m, which can be described as a dangerous zone in respect of the second and third degrees of rock burst hazards;
- Other sections of the excavation that are above 220 m in length can be classified as those within the first and second degree of the rock burst hazard scale and are the least vulnerable to the effects of rock bursts.

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