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Assessment of Seismic Hazard in Relation to Rock-Burst Prevention Modifications in KGHM Polish Copper JSC Polkowice - Sieroszowice Mine, Poland

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Abstract. The Polkowice-Sieroszowice mine is one of three underground copper ore mines in Poland. These three mines belong to KGHM Polish Copper JSC, excavating one of the largest copper ore deposits in the world. The deposit is situated in the south-western part of Poland in the Lower Silesia province. Due to the specific and difficult geological-and-mining conditions in the three mines, seismic events occur which often result in an excavation serious damage defined as the rock-burst or elastic recovery. Such dynamic phenomena have been occurring since 1972 and have posed the most dangerous natural threats in underground workings. Therefore, the mining technology has to take the account of seismic hazard prevention. Numerous preventive measures adjusted to the conditions prevailing in the given operating field have to be applied so that the hazards can be mitigated, fought or limited. The appropriate choice of prevention activities must be preceded by measurements and observations, which constitute different methods for identifying, predicting and assessing the condition of the rock mass as well as for evaluating the protection effectiveness. In the Polkowice-Sieroszowice mine the rock-burst prevention involves: assessment of rock mass state and active, technological, and organizational-technical methods for combating the hazard. The active prevention consists in blasting works which provoke the rock mass to distress itself and thus to reduce its capability to accumulate elastic energy. The technological prevention embraces yielding the edges of the walls and pillars in the place of development, the extraction of the deposit with a wide opening of the front and the adjustment of the size of the technological pillar to the local geological and mining conditions. The organizational-technical measures introduce after-blasting waiting time and high hazard zones where the number of employees should be reduced. The influence of changes and improvements in the prevention activities on the seismic hazard was analysed and determined. The effectiveness of prevention methods was assessed in connection with their modifications, which concerned certain elements of active methods, the pillar size changes and alterations in the frequency of rock mass observations. Most of these modifications resulted from the operational progress and had a little impact on the seismic activity. Nevertheless, the effectiveness of such alterations was calculated. The research was carried out for one mining division in the Polkowice-Sieroszowice mine over the period of 2013-2015 years. The increase in the effectiveness of seismic/rock-burst prevention in most cases resulted in reduction of seismic activity.

1. Introduction

In the copper ore mines owned by the KGHM Polish Copper JSC, seismic shocks and their effects defined as rock bursts have constituted the most dangerous threat since the first moment of exploitation. The seismic hazard is manifested by seismic events i.e. rapidly released seismic energy, caused by violation of the rock mass balance. Seismic shocks can result from natural factors for example changes in the Earth interior or from human activity such as deposit extraction. Shocks triggered by exploitation are called mining-induced tremors. Seismic events and their results can be spontaneous i.e. induced by exploitation works (mining-induced) or provoked (blasting-induced) i.e. induced deliberately with blasting works to release accumulated energy and thus to relief the stress of a rock mass.

The first substantial energy in the KGHM's copper mines was released in 1972 in the Polkowice-Sieroszowice mine and since then numerous activities have been undertaking to determine causes of this phenomenon and to develop preventive methods. Seismological observations carried out with mine seismic networks have been used to recognize and investigate the threat. The violent cracking of the strong rocks found in the roof in the place of exploitation was considered the prime reason of shocks. Rock bursts are defined as the damages of mining workings caused by seismic shocks. The aforementioned event in 1972 resulted in the first rock burst. The significant number of observations indicated that most rock bursts occurred at exploitation fronts, in advance of a cutting line or near gobs. Moreover, the pillars with a width of 20 to 25 m were considered prone to damage and outbursts of rocks took place not in a roof but in side walls. The rock-burst hazard makes it necessary to identify and establish specific operational conditions which include geomechanical parameters of rocks, nearby operations, mining systems, tectonics and thickness of dolomites and anhydrites. In the Polkowice-Sieroszowice mine rock-burst hazard has been significant, for example in years 2008-2011 sixteen rock bursts took place there. Such seismic activity has to be monitored and controlled, therefore preventive measures are implemented. They include evaluation, fighting, limitation and mitigation of the hazard and also assessment of the prevention effectiveness. The rock-burst hazard can be assessed with the use of the following activities: geological recognition of a deposit, mining seismology, evaluation of mining conditions, measurements of manifestation of rock mass pressure, and underground observations. Preventive operations are incorporated in mining technology and embrace active, technological, technical and organizational methods. An appropriate exploitation project is the most effective and least expensive preventive method, next the proper mining technology as well as immediate and organizational methods together with constant monitoring of changes in the state of the threat. Blasting technology is used to excavate copper ores primarily group shooting method. Active preventive operations embrace the group winning blasting of the maximum number of shot faces, winning-relaxation shooting in advance of a front line, and relaxing blasting in a floor.

An assessment of the effectiveness of rock-burst prevention related to its modifications poses the prime objective of the paper. Therefore, geological and mining conditions, seismic activity as well as preventive methods in one mining division in years 2013-2015 were depicted and analysed. Moreover, changes in preventive operations were presented and related to seismic and rock-burst hazard. The active methods were evaluated by means of percentage of blasting-induced shocks and their energy, the technological ones-with the use of spontaneous shock epicentre location in relation to an exploitation front and organizational methods-by means of 24-hour distribution of seismic activity.

2. Research area description

The KGHM Polish Copper JSC has been producing copper and silver for more than fifty years. Nowadays it operates in Poland, Canada, the USA, Greenland and Chile. In Poland, exploitation is conducted in three mines namely Lubin mine, Rudna mine and Polkowice-Sieroszowice mine (figure 1). The proved reserves of copper rank as eighth in the world and these of silver as third. Over 30 million tons of copper ores containing approximately 2% of pure metal and significant amounts of

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silver are mined annually. The average copper content reaches about 1.8% and silver amount is around 51g/Mg [1].

The copper ore deposit is situated within the Fore-Sudetic Monocline on its southern edge, in the south-west part of Poland in Legnica-Glogow Copper Belt (figure 1). In the south-west, the faults of the Central Odra form the boundary between the monocline and the Sudetic block, while in the north-east the monocline borders the Szczecin-Lodz synclinorium. In the east there is the Silesia-Cracow monocline. The bedrock of the Fore-Sudetic Monocline is made of proterozoic metamorphic rocks such as crystalline shales, gneisses, granite-gneisses, phyllites, amphibolites and of Carboniferous sedimentary rocks. They are covered by Permian and Triassic sediments. The third stratigraphic unit that builds this monocline is a thick layer of Cenozoic sediments of sub-horizontal location. The rocks including copper mineralization come from the Permian period (the youngest period of the Paleozoic era) while the deposit rocks are dated to the borderline of the Rotliegend and Zechstein i.e. between the Lower and Upper Permian (figure 1). This period was a time of a radical change in the rock sedimentation environment. In the Lower Permian, the area of the deposit was a dry sandy desert, which was quickly flooded by the highly saline waters of the shallow sea. As a result, copper-bearing rocks are represented by sandstones that were created in a desert environment, as well as dolomites and copper-bearing shale, which are of marine origin [1].

The Polkowice-Sieroszowice mine was established in 1996 by merging two separate mining plants i.e. Polkowice and Sieroszowice. In 1963 the shaft Polkowice P-II was deepened and thus this date determines the establishment of the Polkowice mining plant, while the Sieroszowice mine began to function as a separate enterprise in 1980. The Polkowice-Sieroszowice mine possesses three mining areas i.e. Polkowice, Sieroszowice and Radwanice-East [1, 2].

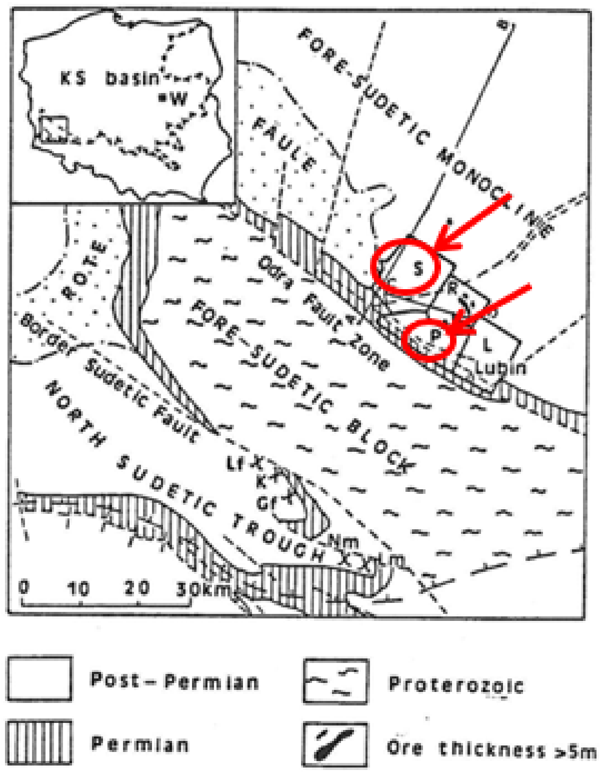

Figure 1. Location of mines and geological structure of Legnica-Glogow Copper Belt [1], S-Sieroszowice mining area, P - Polkowice mining area, R-Rudna mining area, L-Lubin mining area.

3. The G-23 mining division

The G-23 division of Polkowice mining area is located in the northwest of the GG-3 region. There are four mining fields (C, D, G and I). The analysis of seismic hazard was carried out for three fields operated in years 2013-2015 i.e. C and G fields and D1E level in the D field. The C field is bounded from the north by a drive, from the west-by inclined drifts, from the south-by a road, and from the east-by the gobs of the G-21 division. The G field is bounded from the north by a haulage road, from the west-by inclined drifts, from the south and east-by ventilation drifts. The D1E level is bounded from the north by a ventilation road, from the south-by an inclined drift, from the west-by inclined drifts separating the D1E level from D1W one. The copper ore deposit is opened up with two shafts, as well as roads and drifts. The room-and-pillar mining system with roof self-deflection (J-UG-PS) is used to excavate ores. This method should be used to mine pseudo-seam deposits with the thickness of 4.5 to 6 metres and inclination up to 8º. Moreover, roof bolting can be applied as a support system. The length of an exploitation front should be at least 200 metres. If the thickness of a deposit is less than 4.5 metres, mine workings should be made close to a roof. Ahead of the front, cutting is performed to make the pillars and the solid edge yield. Therefore, the pillars yield and work in the non-destructive state and are called technological. The third level of rock-burst hazard, which is the highest one, is established for the G-23 division. The deposit is cut into rooms and pillars with simultaneous separation of technological pillars of 5-9 metres by 6-16 metres dimension. These pillars' longer side is perpendicular to the front line and protect the roof of mined-out area. The mine workings made during the cutting stage should be up to 6 metres wide and up to 4.5 metres high depending on the deposit thickness.

4. Results and discussions

The seismic activity in the G-23 division was high over the period of 2013-2015 years. So, it was necessary to apply a number of prevention activities embracing technological, active and organizational-technical methods for fighting, mitigating and limiting the rock-burst hazard.

4.1. Seismic activity

A seismic shock was defined as a seismic event with energy of at least $1\cdot10^3$J whereas the energy of a high-energy shock reaches at least $1\cdot10^5$J. In G-23 division, in 2013 there were 631 shocks and their total energy reached $2.58\cdot10^8$J. In 2014 the number of shocks increased to 723 and their total energy fell to do $1.46\cdot10^8$J compared with 2013. In 2015 the number of shocks increased to 855 and their total energy also increased and reached $1.93\cdot10^8$J compared to 2014. Over the period of 2013-2015 (table 1, figure 2) there were 2209 shocks of which 257 were high-energy ones and accounted for 12% of all shocks. The total energy of shocks was $5.97\cdot10^8$J of which $5.68\cdot10^8$J belonged to the high-energy ones and accounted for 95% of the total energy. In 2013 the energy per one shock was $4.09\cdot10^5$J, in 2014 it decreased to $2.02\cdot10^5$J and in 2015 it decreased to $2.26\cdot10^5$J. In years 2013-2015 the average energy per one shock was $2.70\cdot10^5$J. It can be said that the total seismic energy was substantial in 2013, then it decreased by 50% in 2014 and increased by 30% in 2015. Whereas the number of shocks increased by 50% (table 1, figure 2).

Table 1. Seismic activity in the G-23 mining division in years 2013-2015.

Years	Number of shocks	Energy of shocks, J	Energy for one shock, J
2013	631	$2.58\cdot10^8$	$4.09\cdot10^5$
2014	723	$1.46\cdot10^8$	$2.02\cdot10^5$
2015	855	$1.93\cdot10^8$	$2.26\cdot10^5$
2013-2015	2209	$5.97\cdot10^8$	$2.70\cdot10^5$

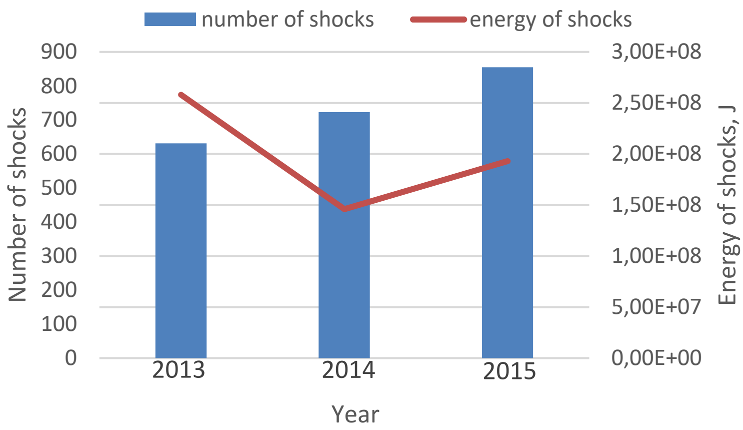

Figure 2. Seismic activity in the G-23 mining division in years 2013-2014.

In years 2013-2015, there were fourteen rock bursts of which eight were induced deliberately (provoked) with blasting and 6 were spontaneous (induced by mining). In 2013 four rock bursts occurred (one spontaneous and three induced), in 2014 six ones occurred (two spontaneous and three induced), and in 2015 there were four rock bursts (three spontaneous and one induced). These events took place at the depth of 810 or 700 metres. Four of them occurred in the shaft pillar (ACG fields), five were in II block in ACG fields, two were in III block in ACG fields and four of them took place in D1E field. The most significant energy of $9 \cdot 10^7$J was released on the 22nd of February in 2013 during the rock burst in the shaft pillar and the least energy of $1.2 \cdot 10^6$J was emitted with the induced rock burst on the 14th of September in 2013 in the shaft pillar too.

4.2. Rock-burst prevention and its modifications

The rock burst prevention is an inseparable element of the exploitation technology and includes the recognition and fighting of rock bursts. Methods for assessing the condition of the rock mass in the G-23 division are based on visual and acoustic observations of cracks in the roof, floor cracks and uplifts, acoustic effects, events during the drilling process, voicing of the rock mass, cracks and loosening in the sides of pillars and intensity of their development, symptoms of delayed passing into non-destructive state, water leakage from the roof and floor, proper supporting construction and its behavior, the process of separation of the roof rocks. Precise information on the state of hazard is obtained by measuring the convergence of excavations in the working zone of the front (at least 3 times a week), measurements of seismic acoustic activity after face shooting (once a day), continuous recording of seismic activity and analyses of passive seismic tomography results (at least once a month).

The threat is mitigated with the use of various methods. Technological methods include making the edges of solid and pillars on the cutting line yield, using systems with a wide open front, adapting the dimensions of technological pillars to geological and mining conditions. Organizational and technical methods encompass identification of the geological structure of the rock mass, adjustment to the conditions, order and direction of exploitation, selection of proper measurement and observation methods, cutting with the aligned line of faces, exploiting long fronts, establishing the special hazard zones and choosing the time to wait after blasting and seismic shocks. The active methods embrace group shooting of faces at their maximum number (shock shooting), winning-relieving blasting in the solid, also with maximizing the number of faces, stress shooting in the floor and blasting long holes in the roof.

The aim of the active prevention is to relieve stresses in the rock mass or to provoke a shock or a rock burst. Blasting works are carried out in the faces of chambers and belts to mine the ore. In order to stimulate/provoke the rock mass relaxation, blasting works are also used in the sides of the pillars and in the floor of the roads. In the mining of copper ore, no roof caving is induced to relieve the stress, as it did not bring the expected results. Winning and shock blasting in the faces is applied on exploitation fronts and brings the expected results. In addition, such activities relieve the impact zone of operating pressure and thus can generate dynamic seismic events. Simultaneous firing several to a dozen or more faces is essential in these activities. This is due to the fact that the blast holes are located in the operating pressure zone, not as in the case of the roof caving in the area of the relaxed and separated rock mass. In the winning and relieving works in the face, both mining holes as well as longer and wider stress relief holes are made. This allows one to fire more explosives in faces and relax the larger area of the deposit. Provoking rock mass relaxation with group blasting works consists in the simultaneous deprivation of supporting the roof layers on a fairly long section of the front and a change of the stress from tri-axial to uniaxial in the part of the deposit. If the roof loses support on a long section of the front, it will mean the simultaneous application of an additional load to the next heavily loaded deposit zone. It can cause rock bursts, but only by simultaneously firing at least a few or even several dozen faces lying next to each other. Between 6 and 15 faces are usually fired simultaneously for technical and organizational reasons. Simultaneous firing of concentrated faces takes place on subsequent sections of the exploitation front. The effectiveness of provoking a rock mass to shake depends also on the state of stresses on the front of the line of faces and on the length of the front section in which the ancestors are fired. Preventive methods based on provoking dynamic events by shooting mainly in the deposit allows one to control the time of occurrence of dynamic phenomena. Based on the previous experience in the KGHM mines, it was found that group shooting of faces provoke mining shocks effectively. After provocative blasting, a specific waiting time is implemented [2, 3, 4, 5].

In the G-23 division, modifications in the rock bursting prevention were implemented depending on the geological and mining conditions and the course of operation. Most often, the number of group blasting and shot faces were modified, sporadically the dimensions of technological pillars were altered, and some elements of measurement and observation methods were changed.

In the G-23 division, the strict rules of shooting were set. These included maximizing the number of faces to be shot and selecting their number to maintain a level line of cuttings. Blasting cut and stress relief holes were used in the main faces. When this was impossible, an increased charge of explosives was used in all holes in the face, as in the cut and stress relief holes. When it was justified, at the same time with shooting faces, stress relief blasting was performed in the floor, making blast holes along technological pillars or in the axis of the excavation. The waiting time was established for a minimum of 6 hours after shooting in the area between the front and the near solid part, as well as in two workings located up to 50 m from the front. In the rest of the front, the waiting time was at least 2 hours. The optimal time after shooting in the technological pillars during their liquidation and after blasting at a distance of more than 150 from the front line was two hours. The length of the waiting time was not changed over the years 2013-2015.

Modifications of technological methods concerned mainly the adaptation of the dimensions of technological pillars to given geological and mining conditions. From January 2013 to the end of May 2014, these pillars' had dimensions of 6x10 metres. In June 2014, in the C and G fields these dimensions were not changed, but in the right part of the D1E level they were altered and fixed at 6x8 metres and in the left part of this level these dimensions were changed to 7x10 metres. Whereas the cutting of the solid between the I-1 ventilation road and the D-45E drift was based on the pillars with dimensions 5-10x8-16 metres. These changes were retained until the end of January 2015. In February 2015 the size of pillars in I and II blocks was changed to 6x9 metres, the rest remained unchanged until the end of April 2015. In May 2015 the dimensions of the technological pillars within the left part of the D1E level were changed to 6x9 metres until November 2015, when they were changed to 6x11 metres. These dimensions were maintained until the end of December 2015.

Modifications of group blasting works consisted mainly in the change of the number of shooting works and the number of faces fired in each shooting (table 2). The average number of faces shot in one shooting per one month was also calculated. In 2013, 2603 faces were fired in 327 blasting works, on average, 8 faces were shot per one blasting. There were 631 shocks with a total energy of $2.58 \cdot 10^8$J including 65 high-energy shocks. In 2014, the number of shocks increased to 723, and their energy decreased to $1.46 \cdot 10^8$J in comparison with 2013. The number of high-energy shocks was 55 with a total energy of $1.36 \cdot 10^8$J i.e. there were fewer events and less energy than in 2013. In 2014, compared to 2013, fewer shootings were done in fewer faces i.e. 151 works in 1726 faces, on average 11.4 faces were blasted per one shooting. In 2015, the number of shocks increased to 855 and the energy also increased and amounted to $1.93 \cdot 10^8$J compared to 2014. There were 137 high-energy shocks with total energy of $1.81 \cdot 10^8$J more than in both 2013 and 2014. In 2015, the fewest number of blasting was performed and the fewest number of faces was fired i.e. 1326 faces were fired in 101 blasting works, on average there were 13.1 faces per one shooting. It seems that fewer group blasting works and more faces shot per one blasting cause more high-energy shocks with more total energy to occur. This may also be favoured by the greater number of faces fired in a single shooting. It indicates that the increasing effectiveness of group blasting works is connected with the decreasing number of blasting works and the increasing number of faces per one shooting. The rock mass relaxes more efficiently in this situation.

Table 2. Number of group blasting works and shot faces in one year over 2013-2015 period in the G-23 mining division.

Year	Number of blasting works	Number of shot faces	Average number of faces shot in one blasting
2013	327	2603	8
2014	151	1726	11.4
2015	101	1326	13.1
2013-2015	579	5655	9.8

4.3. Rock-burst prevention effectiveness

The justification for the introduction of changes in the rock burst prevention as well as the determination of the prevention effectiveness were based on the assessment of individual preventive methods. The degree of effectiveness of rock burst prevention may indicate a potential increase or decrease of the seismic hazard. The evaluation of effectiveness makes it possible to determine whether a given preventive method is applied in an appropriate manner and to a sufficient extent, and whether modifications should be introduced in it in order to improve safety and prevention effectiveness. The simultaneous analysis of effectiveness and seismic activity allows one to assess the risk of a rock burst [4, 5]. The analysis took into account the years 2013-2015. The effectiveness of technological, organizational and active preventive methods was assessed.

4.3.1. Technological methods of rock-burst prevention. To assess the effectiveness of technological methods, the account of the location of the epicentres of spontaneous seismic shocks in relation to the working front was taken (table 3). Possible locations of these epicentres belong to three zones in the field of exploitation: A – ahead of the front (in the solid), B - on the operational front, C - in the gobs. The purpose of the technological methods is to conduct exploitation and control the roof so that the energy can be released slowly and gently. The occurrence of seismic shocks only in the gobs (C) is the most expected, while the most dangerous are shocks occurring ahead of the front (A); they often cause strain rock bursts. The percentage of location of the number and energy of shocks in each zone was calculated. This way the effectiveness of bringing the rock mass to a non-destructive condition as a result of proper exploitation and reduction of stress accumulation zones was assessed (table 3). In 2013, most shocks occurred in the zone (B) of the operational front (76%) (table 3). The occurrence of shocks in zone B is predictable to a certain extent, but they may increase the threat in the field. Particularly dangerous shocks occur ahead of the front (A) and they constituted 19% of all events. Seismic events in the gobs zone (C) posed only 5%. Energy released in the solid (ahead of the front) (A) was not substantial (7%), and the largest amount of energy was allocated on the front (92%), and only 1% of the whole energy was in the gobs. The most number of shocks in zone A took place in April. At that time, a modification was introduced in shooting which consisted in blasting all active faces, although there were very few of them (from 2 to 6). However, no changes were made to the technological prevention. In 2014, compared to 2013, the number of shocks decreased in the A zone (15%) while the energy in this location increased (41%). Again, the most shocks took place directly on the operational front (80%) with an energy share of 56%. The percentage, both of number and energy of shocks in the gobs, increased slightly, to 5% and 3% respectively. In June and August in 2014, the large number of shocks in the A zone was recorded i.e. 15 shocks in each month. There were no modifications of technological methods at that time, so it can be concluded that other factors influenced that unfavourable shock location. In 2015, the most advantageous percentage of number and energy of shocks in the solid (A) was observed, 8% and 7% respectively. Invariably, the most shocks occurred directly in the area of exploitation front (88%) with an energy share of 89%. In 2015, compared to 2013 and 2014, the number of shocks in gobs decreased to 4% (the smallest percentage during the three years). However, a larger share of their energy was recorded in the gobs (4%). Since February, there had been a decrease in the number of shocks ahead of the front (A). It can be stated that this decrease was due to the change in the size of technological pillars in block I and II (to 6x9 m). This dimension change also positively influenced the presence of shocks in the gobs, they appeared there every month. The number of shocks in the gobs increased especially after modifications of the dimensions of pillars in May in the D1E level. However, no direct impact of the dimension change carried out in November was observed. Over the years 2013-2015, the percentage of the number of shocks in the solid (A) was 14%, and that of energy was also 14%, on the front (B) the percentage of the number of shocks was 81% and that of energy was 84%, while in the gobs (C) there was 5% shocks with the energy of 2%. It can be concluded that the effectiveness of technological prevention was satisfactory, the location of shocks in relation to the front was relatively favourable for combating the seismic hazard. The largest number and energy of shocks were found on the operational front and therefore at a predictable place.

Table 3. Effectiveness of technological prevention related to number and energy of shocks in years 2013-2015 in the G-23 mining division

Zone	A	B	C
Year		**2013**	
Number of shocks/Percentage	90/19%	359/76%	24/5%
Energy of shocks, J/Percentage	$1.13\cdot10^{7}$/7%	$1.49\cdot10^{8}$/92%	$1,62\cdot10^{6}$/1%
Year		**2014**	
Number of shocks/Percentage	83/15%	450/80%	27/5%
Energy of shocks, J/Percentage	$2.4\cdot10^{7}$/41%	$3.28\cdot10^{7}$/56%	$1.76\cdot10^{6}$/3%
Year		**2015**	
Number of shocks/Percentage	42/8%	470/88%	21/4%
Energy of shocks, J/Percentage	$4.35\cdot10^{6}$/7%	$5.53\cdot10^{7}$/89%	$2.49\cdot10^{6}$/4%
Years		**2013-2015**	
Number of shocks/Percentage	215/14%	1279/81%	72/5%
Energy of shocks, J/Percentage	$3.97\cdot10^{7}$/14%	$2.37\cdot10^{8}$/84%	$5.87\cdot10^{6}$/2%

4.3.2. Organizational-technical methods of rock-burst prevention. It is possible to verify the length of the waiting time after shooting with the use of the 24-hour distribution of seismic activity [4, 5]. During the waiting time no one is allowed to be at the place of blasting. A 6-hour waiting time after blasting operations was used in the C and G fields and a minimum 2-hour time in the D1E level. Most of the shootings were performed between hours 5 and 7 in the morning and between 17 to 19 in the afternoon. The most desirable situation is when most shocks and their energy occur during blasting works or within the waiting time, which ensures safe working conditions. In 2013, the largest number of shocks occurred during shooting or waiting time. On the other hand, the energy in those hours was small, since the most energy was released between hours 13-14 (18.64%) and 16-17 (37.23%), and there were 12 spontaneous high-energy shocks outside the time of blasting and waiting. In 2014, the highest number of shocks was recorded during the shooting or waiting time. Their energy share is 1.09%, 11.69% and 6.96% respectively. Moreover, eight high-energy shocks occurred within the waiting time. In 2015, the most shocks and their energy were observed during the shooting hours; twenty-six high-energy shocks occurred at that time. It can be concluded that the length of the waiting time was determined properly and effectively.

4.3.3. Active methods of rock-burst prevention. The assessment of the effectiveness of active methods of combating seismic hazard and rock bursts was based on the percentage share of the number and energy of shocks induced/provoked in the number and energy of all shocks (table 4) [4, 5]. Seismic shock provocation by blasting works and thus the control of their occurrence time allowed one to increase the safety of miners. In 2013, the effectiveness of provocation of shocks in relation to their number was 25%, and with respect to their energy it amounted to 37%. In 2014, the effectiveness of provocation of shocks in relation to their number was 23%, and with respect to their energy it was to 60%. In 2015, the effectiveness related to the number of shocks was 38% and in relation to energy it reached 68%. In the years 2013-2015, the average effectiveness for the number of shocks was 29% and for energy 52% (table 4). The effectiveness of shock provocation was satisfactory and increased year by year, i.e. with an increase in the number of faces per one shooting and with a decreasing number of shootings per one year. Such a situation could have helped to relax the rock mass with blasting operations.

Table 4. Effectiveness of group blasting works related to number and energy of induced shocks in years 2013-2015 in the G-23 mining division

Years	Number of induced shocks	Effectiveness (number of shocks) %	Energy of induced shocks, J	Effectiveness (energy of shocks) %
2013	158	25	$9.60 \cdot 10^7$	37
2014	163	23	$8.73 \cdot 10^7$	60
2015	321	38	$1.30 \cdot 10^8$	68
2013-2015	642	29	$3.13 \cdot 10^8$	52

5. Conclusions

In June and July 2014, there were three rock bursts, however before that there were no changes in the dimensions of pillars in C and G fields. In February 2015, these dimensions were changed and the number of seismic shocks increased in March. The modifications of the dimensions of the technological pillars in the D1E level probably contributed to three spontaneous rock bursts. After another change in the dimensions of the pillars, a decline in seismic activity was noted. The effectiveness of technological methods determined by the location of shocks in relation to the operational front was satisfactory, as the most shocks and their energy occurred on the operational front where it was easier to predict them. Although the exploitation was conducted in difficult conditions, the number of the most dangerous shocks (the events occurred ahead of the front) decreased in 2015, which meant high efficiency of introduced technological modifications. In the years 2013-2015, the organizational and technical preventive methods fulfilled their role completely. Metody organizacyjno-techniczne w latach 2013-2015 spełniły swoją rolę w zupełności. In 2014 and 2015, the largest number and energy of shocks occurred during the shooting or waiting time. Therefore, no changes were introduced in the length of the waiting time. It can be concluded that the effectiveness of the active prevention increased year by year and in 2015, it reached a very high level. This high effectiveness could be related to the increasing number of faces fired in one shooting and falling number of shootings per one year i.e. the decreasing frequency of blasting works which allowed the rock mass to relax efficiently. The stable number of faces shot each month also had a positive impact on the prevention effectiveness. In the case of active prevention, the principle that the higher the maximum number of faces being shot, the lower the seismic activity, should be fulfilled. The failure to meet this condition was probably caused by other factors that increased the seismic hazard. These included the entry into a zone without mineralization (stone zone), deterioration of roof conditions or other changes in the structure of the rock mass. Small modifications were introduced in adjusting the size of technological pillars and in group blasting works. Most of these changes resulted from the course of mining operation and had a certain impact on seismic activity. It was also found that there was a relationship between changes in the size of technological pillars and the seismic hazard.

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References

[1] S. Bartlett, H. Burgess, B. Damjanović, R. Gowans, and C. Lattanzi, “Technical report on the copper-silver production operations of KGHM Polish Copper JSC in the Legnica-Głogow Copper Belt area of southwestern Poland,” pp. 13-35, 2013.
[2] J. Butra, “Exploitation of copper ore deposit in rock-burst and caving hazards,” pp. 1-278, 2010.
[3] Z. Kłeczek, “Face group blasting as an element of bump prevention in copper ore mines LGOM,” *Mining and Geoengineering*, vol. R 28/issue 3/1, pp. 153-159, 2004.
[4] A. Gogolewska, R. Bartos, “Rock-burst hazard assessment in selected mining districts of Polkowice-Sieroszowice copper ore mine,” *Scientific Works of Mining Engineering Institute of Wroclaw University of Science and Technology, Mining and Geology,* vol. 123/34, pp. 49-62, 2008.
[5] A. Gogolewska, R. Bartos, “Effectiveness of rock-burst prevention methods in selected mining panels in Polkowice-Sieroszowice copper ore mine,” *Scientific Works of Mining Engineering Institute of Wroclaw University of Science and Technology, Mining and Geology* X, vol. 123/34, pp. 63-75, 2008.