GOSPODARKA SUROWCAMI MINERALNYMI

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Determining of water hazard zones for mining exploitation planned in the vicinity of reservoirs in abandoned mines

Introduction

During last years there has been noticed a significant decrease of frequency occurrence of water hazard symptoms in coal mines of the Upper Silesian Coal Basin (USCB) (Bukowski, Bukowska, Haładus 2005; Jureczka, Galos 2008; Rogoż 2004). After the year 2000 there were noticed five cases being the manifestation of water hazard. Two of the above mentioned cases consisted in water inrush (intrusion of water with loose rock material) from fault fissures to mine workings of the Jaworzno mine. Lately noted three incidents were falls with great height with simultaneous water inflow into active mine workings (Kubica, Bukowski, Gzyl 2008) and inflow (inrush) of water with loose rock material into ventilation shaft of KWK Pniówek in the year 2007 (Tor, Jakubów, Tobiczyk 2008). The incident that took place in 2008 was the catastrophe in the ventilation shaft of the KWK Szczygłowice. As a result of continuity interrupting and partial collapse of shaft pipe lining the self-backfilling of the shaft pipe with formation of carboniferous overburden and destroyed elements of surface buildings took place. In case of both shafts the hazard resulted from the formations of overburden deposit series.

The first of occurrences noted during last few year related to the region of coal exploitation planned in the vicinity of the reservoir with total capacity of about 7.2 m^3 of water formed in the neighbouring abandoned mine. The incident was the result of penetration of loose rock material from the goaf zone after the exploitation of the seam 510 and accompanying water outflow (to 1.0 m^3/min) to the mine workings. The piercing of water from the reservoir was possible. Despite the elimination of water hazard coming from water reservoir

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the plans of future exploitation within the endangered area should to be verified. The methodology developed in article can be used to indicate the safe distance between designed mine workings and sources of water hazard for similar conditions.

1. The characteristic of water hazard state for mining exploitation conducted in the vicinity of reservoirs of great capacity

Since the period after the World War II, water hazards have referred to inrushes of water or water with loose material. In the year 1961 there were 30 such occurrences. During 70's and 80's of the XX century better methods of fighting against water hazard were searched. There were also issued some instructions and regulations tending to limit the number of intrusions to active mine working. In the years 70's of XX century while the package of research methods and regulations concerning conducting of mining works in conditions of water hazard the amount of coal exploitation reached the maximal level – about 200 mln tons per year. The exploitation was conducted mainly by the system with roof rocks fall what resulted in significant transformation of geological environment as well as on the ground surface and intensive drainage of the rock mass. Generally between the end of 1961 and the beginning of the 90's of XX century all efforts were connected with rock mass and mine workings dewatering as well as active mine working protecting against water hazard. The abandoning of mines and all the more forming of water reservoirs with their size equal to the whole flooded mine as well as mining exploitation in the vicinity of such reservoirs were not taken into consideration (Bukowski 2007).

In the 90's of XX century the abandoning process of numerous Polish coal mines was taken up. Mines abandoning was connected with changing of coal sources base (Jureczka, Galos 2008; Kulczycki, Sowa 2008) and start of the process of their partial or total flooding. Even then the consequences of these actions were not considered in the aspect of plans of exploitation in the vicinity of such reservoirs but rather in the aspect of necessity of controlled water reception or maintaining of dewatering on the level thought to be safe for active mines. The possible consequences for the surface were also considered (Bukowski 2006; Rogoż, Bukowski, Górka, Posyłek, Solik-Heliasz, Staszewski 1995). Since then in numerous mines there have been formed underground reservoirs with their capacities up to millions of cubic meters of accumulated water. The capacities of the above mentioned reservoirs cause that their abandoning in accordance with executive regulations concerning geological and mining law was found to be unrewarding in the present economic conditions.

The only methods of defense against water hazard in active mines that would be willing to conduct the exploitation of seams in fields in the vicinity of such reservoirs is existence of safety pillars (often these are only border pillars), hydrotechnical buildings (water dams and corks), dewatering systems in abandoned mines, for example specially built well dewatering system (deep well pumping stations) and individual systems of active mines – dewatering system by mining method. The system of mine workings designed for emergency dewatering may be helpful. In every case the possibility of water intrusion or water outflow from the reservoir into mine workings of an active mine through the rock mass untight because of post-exploitation influences should be taken into account. Taking into consideration provisions of the geological and mining law, the situation when there is no possibility of the reservoir dewatering causes that earlier conducted mining works limit the possibility of the safety pillar indicating or there is even no such a possibility. For planned mining works it is then necessary to make a decision to conduct mining exploitation or not.

2. The example of a safety pillar for the designed multilayered mining exploitation conducted in the vicinity of reservoirs with great capacities

The example of such a difficult situation when the possibility of exploitation commencement hanged in the balance is the area of one of mines of Katowice Coal Holding (KHW S.A.) (fig. 2.1).

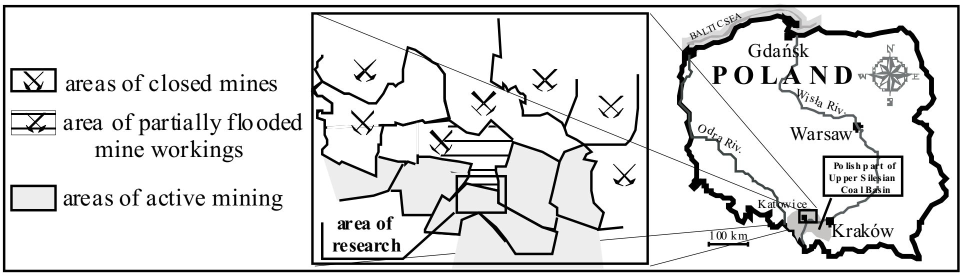

Fig. 2.1. The situation sketch of location of the exemplary considered area of active mine with respect to neighbouring mines

Rys. 2.1. Szkic sytuacyjny położenia przykładowego rozpatrywanego obszaru kopalni czynnej względem kopalń sąsiednich

In the year 2007 the fall of roof rocks from the goafs after the exploited roof layer (III) of the 510 seam to the active mine workings of the central layer (II) of the above mentioned seam. Simultaneously with the fall it came to the intensive outflow of water with loose rock material. In connection with the above mentioned there was a concern that the pillar separating the field in the active mine and flooded mine workings in the neighbouring abandoned mine was disturbed.

Within the field in the vicinity of water reservoir mine provide exploitation in two layers of the seam 510 (the total thickness of the seam is about 11.0 m) as well as in the seam 501 with its thickness from 6–7 m. It was assessed that in both seams within the perspective group there are recognized about 9.7 mln tons of energetic coal (operational sources) with the market value of 330–350 zł/t. The total value of the coal is minimum 3.2 mld zł. Since the exploitation within the layer III (sub-roof layer) in the seam 510 the hazardous situation for the exploitation planned in seams 510 and 501 was recognized to be complicated. The above mentioned was connected with the change of height of water rebound in mine workings of the partially flooded abandoned mine after exploiting of the layer III of 510 seam in the active mine.

2.1. Sources of water hazard for designed mine workings

The source of water hazard for the mining exploitation designed in the perspective field within the seam 510, and in the subsequent prospect within the seam 501, may be:

1) With reference to waters with unlimited easiness of movement (group I of the sources of water hazard):

— the reservoir formed in mine workings of abandoned, partially flooded mine,

— goafs of sub-roof layer proofing with ash-water mixtures,

— water reservoirs in goafs and mine workings located upper.

2) With reference to waters with limited easiness of movement (group II of the sources of water hazard):

— reservoirs in so-called Weber's voids,

— gravitational waters contained in the sandstone beds in the roof of the seam,

— the zone of south fault being in the contact with watered mine workings.

Among the sources of water hazard of the group I watered goafs in seams located upper are not of no importance. Similarly minor importance was attributed to goafs of the layer III of the seam 510 filled with ashes and water. Undoubtedly the water reservoir within goafs of the neighbouring abandoned mine is the biggest and the most serious source of water hazard. It is located to the north from the perspective field from which it is separated by the fault zone of the so-called south fault with its run close to meridional throwing the layers to the South of about 25 m (fig. 2.2).

Because of the direct connection of the fault zone with flooded mine workings located within the reservoir, the perspective field is separated from the fault by the safety pillar that was established for the exploitation of the III layer of the 510 seam. The pillar was indicated in conditions of water table location in the reservoir on ordinate of about –350 m, exploitation planned up to 3 m height in only one layer of the seam 510 and under conditions of occurrence in the fault zone of rock mass tremor with their energies more than 10^5 J (vide: Kubica, Bukowski, Gzyl 2008). In the above mentioned conditions the indicated pillar was 45 meters wide. The possibility of waters rebound in the reservoir formed in abandoned mine as well as mining exploitation in the remaining two layers of the seam 510 and within the seam 501 were not predicted. After indicating of the pillar, there was conducted the exploitation with fall of roof rocks in the layer III of the 510 seam (the mine does not have a possibility to conduct the exploitation with backfilling). After the above mentioned exploitation the mine designed the exploitation within the layer II of the seam 510 (middle) predicting that in the future the exploitation may also be conducted within the layer I (floor layer) as well as within the seam 501 located about 45 meters higher. Since the pillar was

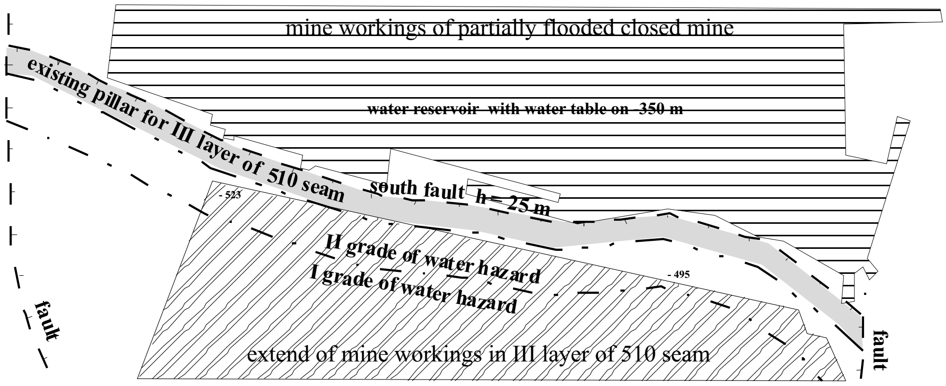

Fig. 2.2. Situation sketch in the area of water reservoir formed in the abandoned mine with safety pillar separating mine workings within the layer III of the seam 510 from the zone of south fault before water table rebound in the reservoir to the ordinate of –200 m

Rys. 2.2. Szkic sytuacyjny w rejonie zbiornika wodnego utworzonego w kopalni zlikwidowanej i filara bezpieczeństwa rozdzielającego wyrobiska górnicze III warstwy pokładu 510 od strefy uskoku południowego przed spiętrzaniem zwierciadła wody do rzędnej –200 m

indicated, the water in the abandoned mine has been rebound up to the ordinate of –200 m. Water table is maintained on the above ordinate by the well dewatering system. Currently the pressure of water in the abandoned mine is of 3.3 MPa on the level of safety pillar, alongside the south fault, and on the level of mining works in the active mine. In the reservoir of the abandoned mine about 7 mln m^3 of water are stored. The inflow of even part of these waters to the mine workings of an active mine with an intensity exceeding pumping abilities of its dewatering system would mean the flooding of the active mine up to the height of water levels equalization or to the height of the next and lowest connection of this mine with another one.

The sources of water hazard of group II are significant only for the safety of single mine workings. The example is dewatering of the Weber's void of waters seeping to it from sandstones located above. The result of the above mentioned dewatering was water inflow with watered rock material to the active mine working within the layer II. The inflow was identified and controlled quickly. Generally the south fault have more important role in the aspect of water hazard in the exemplary mine. Despite its filling with tectonic breccias and clay material it has direct contact with watered mine workings in the abandoned mine.

2.2. Safety pillar determining for designed mine workings

So far safety pillar with its width of 45 m left by an active mine has effectively protected this mine in case of water hazard. However it was not predicted in case of double increase of water pressure in the reservoir as well as it was not considered in the aspect of taking up new exploitation within the seam 510 and all the more within the seam 501.

Currently active mine predicts mining works in the layer II of the seam 510 under the goafs of the post-exploited layer III. Assuming that for the next- bottom layer I, the width of the safety pillar is estimated as for the pillar parallel to the beds and for the source of water hazard with unlimited easiness of water movement, the width of this pillar counted on the basis of the formula 2.1 (Konstantynowicz, Bromek, Piłat, Posyłek, Rogoż 1974) for the layer II shall be D = 40.3 m and for the layer I D = 60 m.

$$D = G\sqrt{60p + 0.15G^2 \sin^2 \alpha + 0.4G^2 \sin \alpha} \quad (2.1.)$$

For the seam lying with small gradient ($\alpha < 15°$) it is allowed to use the shortened formula:

$$D = G\sqrt{60p} \quad (2.2.)$$

where:

- D – critical dimension of the pillar (width) [m],
- G – exploitation height of layer [m],
- p – water pressure in the source of hazard [MPa],
- α – angle of the gradient of the seam [degrees].

Thus counted critical dimension of the pillar for layer II is smaller than already indicated value for safety pillar, however is larger for the layer I. In the counted dimension of the pillar for both layers I and II the possibility of high energetic tremors within the zone of south fault was not taken into consideration. Considering the possibility of rock mass violation by tremors of layer I and II, just as for the layer III, the width of the pillar was doubled. Doubled critical dimension ($D_s = 2 \cdot D$) shall be equal to $D_s = 80$ m for the layer II and $D_s = 120$ m for the layer I. The above mentioned means that existing pillar for the exploitation within the layer II is about 35 m smaller, and within layer I it is smaller of about 75 m than the dimension of the counted pillar. Calculations were checked by means of the transformed formula by (Rogoż 2004) taking into account tension strength for rocks and resulted in the same outcome (fig. 2.3).

According to executive regulations of Geological and mining law the pillar is understood as part of a rock mass intact with mining works and separating the source of hazard from active mining works. While designing mining exploitation within the layer II (middle) of seam 510 the question concerning what the safety pillar is for this exploitation if roof of the above mentioned layer consists of corridor mine workings as well as goafs of the layer III of the seam 510 should be answered.

Assuming that the pillar shall not be disturbed by mine workings, critical pillar width calculation for the layers I and II projected to exploitation, with existing pillar within layer III, does not have physical and legal basis, thus is pointless. With water rebound up to the

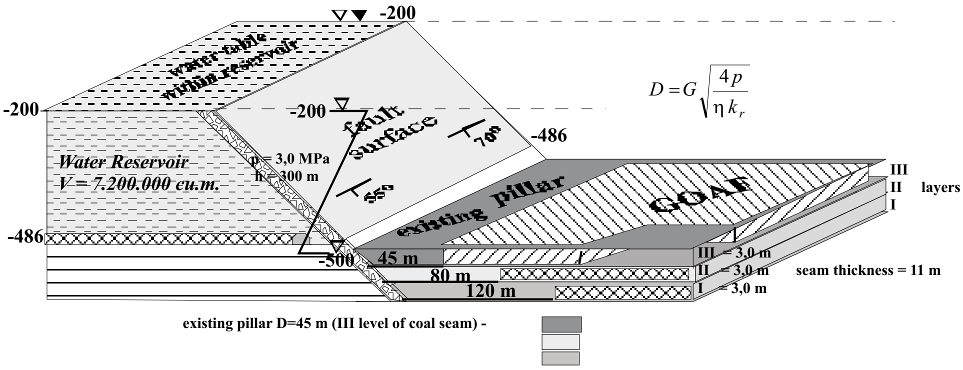

Fig. 2.3. The scheme for the exploitation designed within the fault wall throw in the vicinity of water reservoir of very large capacity and calculations for critical pillar dimension
where: D – critical pillar dimension, G – height of the wall, p – water pressure in the source of hazard, k_r – acceptable tensive stress, $k_r = R_r/8$, R_r – rocks strength for tension, η – coefficient equal 1,33 (according to Slaseriev) with changeable lying of rocks building the pillar and 2,0 with their regular lying (vide: Konstantynowicz, Bromek, Piłat, Posyłek, Rogoż 1974; Rogoż 2004)

Rys. 2.3. Schemat dla eksploatacji projektowanej w zrzuconym skrzydle uskoku w pobliżu zbiornika wodnego o bardzo dużej pojemności i obliczeń dla krytycznego wymiaru filara
gdzie: D – krytyczny wymiar filara, G – wysokość ściany, p – ciśnienie wody w źródle zagrożenia, k_r – dopuszczalne naprężenie rozciągające, $k_r = R_r/8$, R_r – wytrzymałość skał na rozciąganie, η – współczynnik wynoszący 1,33 (wg Slesariewa) przy zmiennym zaleganiu skał stanowiących filar i 2,0 przy ich stałym zaleganiu (vide: Konstantynowicz, Bromek, Piłat, Posyłek, Rogoż 1974; Rogoż 2004)

ordinate of –200 m instead of –350 m in the abandoned mine, with existing pillar with its dimension D = 45 m later exploitation should be discontinued or water pressure in the reservoir should be reduced.

Thus if acting strictly according to executive regulations of Geological and mining law mining exploitation in the vicinity of very large water reservoirs in abandoned mines would not be possible at all. To make such exploitation possible the pressure in the reservoir should be reduced to the value corresponding with the value of critical strength of existing pillars. Because of the time of such undertaking, water pumping costs and costs of its throw it would raise production cost of 1 ton of coal or would make the exploitation uneconomic.

In the above mentioned example there remain 6.5 mln of tons of good quality coal within two layers of the seam 510 (operative deposits) (coals of the type 32.1). Its market value is at least 2.1 mld PLN. Taking into consideration that costs of 1 ton of coal exploitation in given mine accounts for 98–99% of its price (average cost of 1 ton of coal exploitation in Poland is about 210 PLN in the year 2008), actual expected profit may be 1–3 PLN per one ton. Thus estimated profit of coal sale may be equal to about 6 mln PLN.

The decrease of water pressure in the reservoir in mine workings of flooded mine for 3.0–3.3 MPa to 1.5 MPa (without the pumps replacement) thus to the value for which the pillar within layer III was designed, will require pumping of almost half of capacity of a reservoir in an abandoned mine. Assuming that it is about 3.6, mln m^3 of water, with prospective natural recharge to abandoned mine at about 6.5–7.5 mln m^3/min and pumping system effectiveness of about 17 m^3/min it would last about a year. The costs of pumping station working as well as pumping and water draining would amount to 6.5 mln PLN. In case of the necessity of water table lowering as well as pressure lowering to the minimal value on the level of the pillar, time of pumping could double (2 years). Then costs of this operation would amount to over 12–15 mln PLN. Also costs of polluted water discharge should be added to pumping costs. Comparing dewatering costs and expected profit from coal sale the significant financial effort of the mine may be noticed while expected economic effect is doubtful. In case of the necessity of absolute waters pumping the operation will be totally uneconomic.

Thus it was regarded that there should be searched solutions not excluding mining exploitation and simultaneously demonstrating real safety conditions. The works on indicating of a new attitude to mine works designing in conditions of water hazard in the vicinity of very large water reservoirs were undertaken.

3. The methodology of safety zones indicating for designed mining exploitation

As it was indicated in the chapter 3, because of mining works conducting in the roof layer of the seam 510 the determining of a new safety pillar for lower layers of the above mentioned seam is not possible. The reach of mining exploitation influences in conditions of repeated exploitation with significant height, especially with the fall of roof rocks, is almost impossible to be indicated precisely. The fact of indicating of safety index values (s = 8, fig. 2.3) for the calculation of critical dimensions of safety pillars points at the unpredictability of expected reach of exploitation influences in a rock mass. Thus, for the presumable reach of mining exploitation there was conducted a computational simulation of reach of deformation which measures are deformations in a rock mass with various lithological structure. Moreover in a classic manner presented in the chapter 2.2 the safety pillar parallel to the beds lying of barren rocks was indicated.

Calculations of a deformation reach in a rock mass were made for the vertical axis in a rock mass, counting from the roof of exploited seam. In calculations there were used formulas from the Budryk-Knothe theory and empirical formulas for the r_z parameter – radius of impacts dispersion in a rock mass counted from the dependence of main impacts reach radius in a rock mass (Kowalski 1985)

$$r_z = r(z / H)^n \tag{3.1}$$

where:

- r – parameter of dispersion of impacts on the surface (it was assumed in calculations tgâ = 2.0),
- r_z – the horizon in a rock mass determined from the roof of exploited seam,
- n – exponent, it was assumed n = 0,5 (Kowalski 1985).

Horizontal deformations defined by the value of deformation coefficient $\varepsilon = +1.5$ mm/m (for the layer II) and $\varepsilon = +0.3$ mm/m (for the layer I) were assumed as the criterion of the assessment of impacts reach. The calculations have been made for each layer exploitation depth $g = 3.0$ m with exploitative coefficient $a = 0.8$ and the parameter of horizontal displacements proportionality $B_z = 0.4\ r_z$.

The methodical attitude for the determining of safe distance of mining exploitation consisted of usage of results of safety pillar calculation and reach of exploitation impacts dispersion. It was undertaken to indicate the distances of designed exploitation from the edge of source of hazard – zones of water hazard. The edge of water hazard source (reservoir) may be understood for example as the reach of vertical view of flooded mine workings. For the considered example it was assumed that it was the south fault plane with changeable inclination from 55 to 70°. The result of calculation for the critical dimension of the pillar with taking into account a possible influence of rock mass tremors is recognized to be the minimal distance from the fault. However with the above mentioned distance vertical impacts (deformations) dispersion sphere reaches the fault fissure just at the height of slightly more than 40 m above the seam roof. It was possible to be shown only through a graphic visualization (fig. 3.1A).

That is why the safe distance of designed mining exploitation from the source of hazard is the distance guaranteeing that calculated impacts of the exploitation (horizontal deformations) shall not reach a fault fissure below water table in a reservoir of an abandoned mine. Since there is no experience concerning such indication of the distance of source of hazard as well as indication of water hazard areas, it is necessary to observe the course of exploitation within the layer II before the commencement of the exploitation within the layer I, and all the more within the seam 501. Currently estimated values of deformations should be verified with experience within the scope of deformation forming under the influence of exploitation.

The safe distance of mining exploitation determining consists in graphic image of deformation reach between the vertical projection of exploitative mine workings and the source of water hazard. According to the above mentioned criterion (deformations) the safe distance of designed mining exploitation is indicated by the reach of deformation zone with its run tangent to the edge of water hazard source (fig. 3.1B).

The following spheres of water hazard have been indicated on the basis of calculation results for safety pillars parallel to bedding for each layer designed for exploitation as well as on the basis of calculations of rock mass deformations reach and graphic indication of their safe distance from water hazard – water hazard zones (fig. 3.1C):

- dangerous – corresponding with theoretical width of the safety pillar,
- higher risk – corresponding with the zone of rock mass located between a theoretical safety pillar and graphically indicated critical distance of reach of horizontal mining exploitation impacts,
- low risk (safe reach of the exploitation) – located beyond graphically indicated critical distance of reach of horizontal mining exploitation impacts.

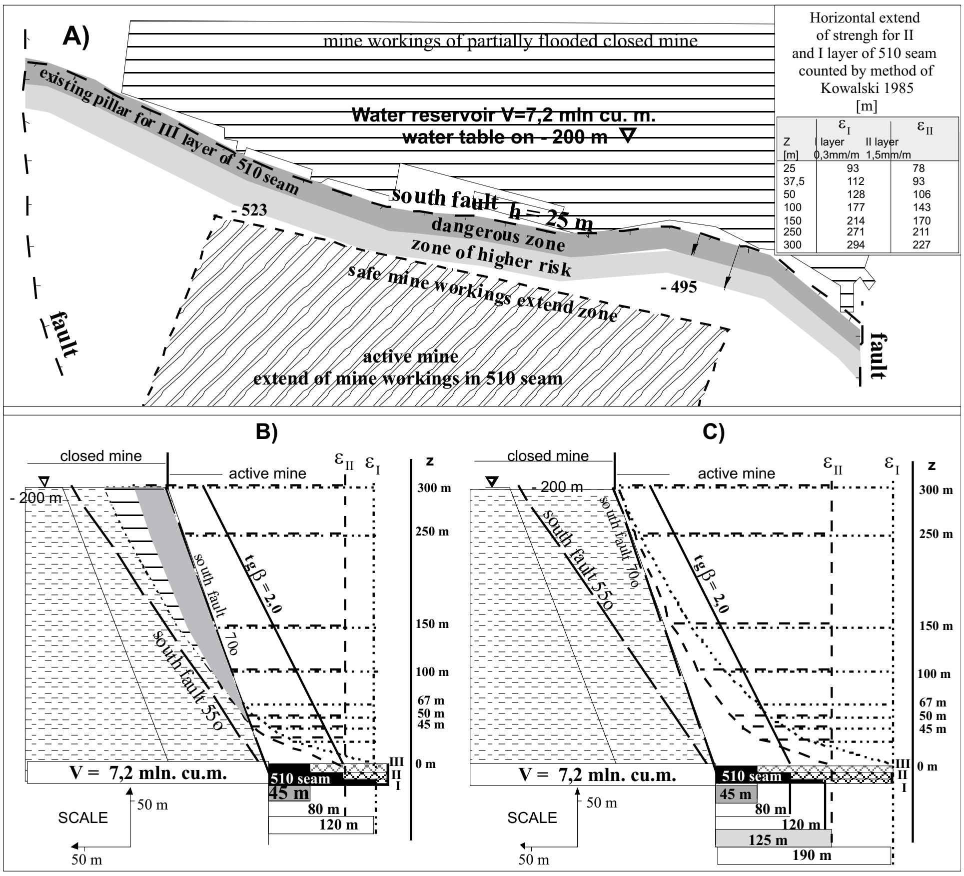

Fig. 3.1. The scheme of safety spheres indication on the maps A), the reach of rock mass deformation while preserving distances of designed exploitation from the source of water hazard according to calculated critical dimension of the safety pillar B), and after graphically position correct of the exploitation front away from a reservoir C)

Rys. 3.1. Schemat wyznaczania stref bezpieczeństwa na mapach A), zasięgu deformacji górotworu przy zachowaniu odległości projektowanej eksploatacji od źródła zagrożenia wodnego wg obliczonego krytycznego wymiaru filara bezpieczeństwa B) i po graficznej korekcie położenia frontu eksploatacji od zbiornika C)

The above mentioned zones indicating bases on the criterion of pillar critical dimension and maximal reach of horizontal deformations in a rock mass caused by conducted and designed exploitation as well as bases on geomechanical premises of rock mass behavior within the area of its exploitation (Bukowska 2009). In the author's opinion an indication of the above mentioned zones is a right measure of prevention for the parts of deposits suitable for exploitation and located in the vicinity of very large water reservoirs. Only the possibility of water filtrating from the reservoir to the direction of active mine workings is predicted. The condition of wider implementation of safe zone indication manner in hard-coal mines is detailed analysis of share and importance of geomechanical factor in deformation zones formation as well as its influence on the possibility of water hazard occurrence. It would be also important to execute the necessary observations and consideration of such attitude to water hazard within executive regulations of Geological and mining law. Activities within the above mentioned scope have already been taken by the Central Mining Institute and AGH University of Science and Technology.

Summary

The article presents non-standard solutions as for the conditions of water hazard assessment. Since many decades there have been accepted methods of the assessment of this hazard and methods of protection against it (Konstantynowicz, Bromek, Piłat, Posyłek, Rogoż 1974; Rogoż 2004). Because of the size of water hazard source and existing of safety pillar indicated for different conditions it was necessary to elaborate the method of safety conditions indicating for designed mining exploitation. With existing safety pillar safety zones were indicated by calculations as well as graphically for multilayered exploitation. It was assumed that from the point of water hazard it is appropriate to indicate a dangerous zone, zone of higher layer as well as zone within which mining exploitation may be designed. Edges of designed exploitation were moved away from the fault fissure for the distance larger than calculated reach of dispersion of exploitation impacts in a rock mass using the following methods: computational, graphic, the method of extrapolation and reach of exploitation impacts dispersion radius adjustment to accepted location of the exploitation front. Thus obtained distance from a fault and also from the reservoir was recognized to be the distance of safe reach of designed exploitation in subsequent layers of a seam. In the author's opinion the acceptance of the attitude to water hazard presented in the work enables to elaborate the rules of mining exploitation for better usage of coal deposits located in the vicinity of reservoirs impossible to be dewatered and abandoned. The method presented in the article should be used in the future for similar conditions of exploitation on the border of active and abandoned mines.

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DETERMINING OF WATER HAZARD ZONES FOR MINING EXPLOITATION PLANNED IN THE VICINITY OF RESERVOIRS IN ABANDONED MINES

Key words

Safety, mining, hydrogeology, water hazard in mines, water reservoir

Abstract

In the article there were presented the changes of water hazard state in coal mines during last several years. On the basis of recognition of conditions of conducted and planned mining exploitation there was presented the example of water hazard assessment for mining exploitation planned near abandoned flooded mines. On the example of planned mining exploitation in the conditions existing in the Upper Silesian Coal Basin there was also presented the methodology of safety zones determining in active mines separating them from water reservoirs with their capacities up to millions of cubic meters of water.

WYZNACZANIE STREF ZAGROŻENIA WODNEGO DLA EKSPLOATACJI GÓRNICZEJ PROJEKTOWANEJ W POBLIŻU ZBIORNIKÓW W ZLIKWIDOWANYCH KOPALNIACH

Słowa kluczowe

Bezpieczeństwo, górnictwo, hydrogeologia, zagrożenie wodne w kopalni, zbiornik wodny

Streszczenie

Przedstawiono zmiany stanu zagrożeń wodnych w kopalniach węgla kamiennego w okresie ostatnich kilkunastu lat. W oparciu o rozpoznanie warunków prowadzonej i projektowanej eksploatacji górniczej przedstawiono przykład oceny zagrożenia wodnego dla eksploatacji górniczej planowanej w pobliżu zatopionych kopalń zlikwidowanych. Na przykładzie projektowanej eksploatacji górniczej w warunkach Górnośląskiego Zagłębia Węglowego zaproponowano metodykę wyznaczania stref bezpieczeństwa w kopalni czynnej od zbiorników wodnych o pojemności liczonej w milionach metrów sześciennych wody.