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EVALUATION OF WATER HAZARD IN HARD COAL MINES IN CHANGING CONDITIONS OF FUNCTIONING OF MINING INDUSTRY IN UPPER SILESIAN COAL BASIN – USCB (POLAND)

OCENA ZAGROŻENIA WODNEGO W KOPALNIACH WĘGLA KAMIENNEGO W ZMIENIAJĄCYCH SIĘ WARUNKACH FUNKCJONOWANIA GÓRNICTWA W GÓRNOŚLĄSKIM ZAGŁĘBIU WĘGLOWYM – GZW (POLSKA)

Water hazard has been accompanying underground mining since the first mines were built. The hazard is particularly often in the areas of mines situated in hydrogeologically outcropped part of USCB and in water rich formations of Cracow Sandstone Series. To plan properly mining actions and technical measures at each stage of life of a mine it is necessary to evaluate hydrogeological and geomechanical conditions and their changes. The conditions determine formation, occurrence and volume of the most serious sources of water hazard. Symptoms obtained in geomechanical tests and observations of forming and dewatering reservoirs of underground water, show that it is necessary to update constantly evaluation and classification of sources of water hazard or the state of water hazard in the coal mines of USCB.

Development of underground mining in 1945-1990, which resulted in a quick increase in production, determined development and the range of influence of mining operations on the rock mass and the influence on the state of drainage and saturation of the rock mass. The result of the changes was an apparent influence on the changes in the state and shaping water hazards in the course of time. Since 1989 economic conditions of functioning of mines have been tightly associated with the conditions and rules of market economy. As a result of each of the so-called restructuring of mining activity a certain number of mining companies was closed, merged or split. The consequence is that in the vicinity of active mines and prospective mining areas, more and more often there are partially or completely flooded abandoned coal mines. Flooded coal mines have changed and still do hydrogeological conditions of their surrounding and force active mining companies to introduce changes in mining activities they are planning and conducting. The current state of flooding mine workings, is a result of realizing previous plans of restructuring mining industry, and all the changes of the state require hydrogeological documentation and evaluation of water hazard.

In the today's conditions of functioning of mining industry, sources of water hazards like water reservoirs in goafs, are one of six main types of sources of hazard, and at the same time the biggest problem and the most serious threat for active mine workings. As the hydrodynamic conditions in the closed areas stabilise and the water piles up close to the surface, an increase in the influence of reservoirs on the state of environmental and public hazard (subsidence, overflowing, flooding, pollution of water in the aquifers located in the overburden and surface water).

As there is a qualitative change in the directions, causes and sources of water hazard, it shall be expected that the changes will tend to increase the threat level from the closed mines. Hence since

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2000 the Central Mining Institute has been focused mainly on methodology research, both laboratory ones of various scale of observation referring to the properties of rocks and rock debris, and in situ ones and forecasting ones accompanied by proposed multidirectional applications of the developed methods in mining and environmental practice. The effect of the works was developing and patenting a few new methods. The effects of works which have been conducted in the last several years were proposed changes in defining water hazard, classifying the hazard and its sources. Classifications of underground water reservoirs, deposits located in the vicinity of reservoirs in closed coal mines and water safety of shafts were proposed. The devised test and evaluation methods have wide practical applications in evaluating water hazard and limiting the hazard, as well as estimating volume of water in reservoirs of closed mines and estimating energy of the water and free methane deposit in the abandoned goafs and mine workings. Their application in hydrogeology plays an important role in estimating volume of water in aquifers built of porous hard rocks. It is also important and applicable in environmental engineering to evaluate volume of water, estimating conditions of its accumulation and flow, and migration of pollution mainly within surface water reservoirs reclaimed with waste rock.

Keywords: water hazard, restructurisation of hard coal mines, hydrogeological properties of rocks and rock mass, methods of investigations, Upper Silesian Coal Basin

Zagrożenie wodne, przez które należy rozumieć: *możliwość wdarcia lub niekontrolowanego dopływu wody (solanki, ługów) albo wody z luźnym materiałem do wyrobisk górniczych stwarzającego niebezpieczeństwo dla ruchu zakładu górniczego lub jego pracowników* jest obecne w górnictwie podziemnym od czasu budowy pierwszych kopalń. Zagrożenie to szczególnie często występuje w obszarach kopalń położonych w hydrogeologicznie odkrytej części GZW (Rys. 1) i w silnie wodonośnych utworach krakowskiej serii piaskowcowej. Aby można było prawidłowo zaplanować działania i zaplecze techniczne na każdym etapie funkcjonowania kopalni konieczne jest dokonanie oceny warunków hydrogeologicznych i geomechanicznych oraz ich zmian. Prowadzenie oceny zagrożenia wodnego zachodzi w warunkach GZW w bardzo zróżnicowanym środowisku geologicznym z uwagi na litologię, właściwości skał budujących górotwór i warunki występowania wód podziemnych. Środowisko to w każdym przypadku poddawane było wpływom działalności górniczej o różnej intensywności, zakresie i czasie trwania czynników wpływu. Różne warunki hydrogeologiczne w różnych częściach GZW i różna intensywność oddziaływania kopalń na tych obszarach prowadziła do zróżnicowanego zawodnienia kopalń, które jest główną przyczyną zróżnicowania wielkości dopływu wody do kopalń i możliwości jej gromadzenia w wyrobiskach. Warunki te w głównej mierze decydują o formowaniu się, występowaniu i wielkości najgroźniejszych źródeł zagrożenia wodnego. Zmiany warunków hydrogeologicznych są z kolei powiązane ze zmianami warunków geomechanicznych (Rys. 1), m.in. przez wpływanie na skład pojemnościowy zbiorników dołowych (Rys. 2) i dróg przepływu wody oraz zmianę właściwości zabezpieczeń przed zagrożeniem wodnym. Przesłanki wynikające z badań geomechnicznych i z obserwacji tworzenia się i odwadniania zbiorników wód dołowych, jak również z istotnych w stosunku do lat przed 1990 r. zmian w funkcjonowaniu górnictwa wskazują na konieczność stałego dostosowywania ocen i klasyfikacji źródeł zagrożenia wodnego oraz stanu zagrożenia wodnego w kopalniach węgla kamiennego w GZW.

Rozwój górnictwa podziemnego lat 1945-1990, którego efektem był szybki wzrost produkcji, zdecydował o rozwoju i zakresie wpływów eksploatacji górniczej na górotwór i wpływie na stan drenażu i zawodnienia górotworu. Skutkiem tych zmian był ewidentny wpływ na zmiany stanu i kształtowania się zagrożeń wodnych w czasie (Rys. 3). Od 1989 r. warunki ekonomiczne funkcjonowania kopalń są ściśle związane z uwarunkowaniami i zasadami gospodarki rynkowej, co spowodowało, że w efekcie każdej, tzw. restrukturyzacji działalności górniczej likwidowano, łączono lub wydzielano pewną liczbę zakładów górniczych. Skutkiem tego, sąsiadem czynnych kopalń i pól perspektywicznych, coraz częściej były częściowo lub całkowicie zatopione zlikwidowane kopalnie węgla. Kopalnie zatapiane zmieniały i zmieniają warunki hydrogeologiczne ich otoczenia, co wymusza na czynnych zakładach górniczych zmiany w planowaniu i prowadzeniu działalności górniczej. Oddziaływanie zbiorników wodnych, które stają się źródłami zagrożenia wodnego jest już widoczne w przebiegu procesu zatapiania wyrobisk górniczych i parametrów, które ten proces charakteryzują. Obecny stan zatapiania wyrobisk górniczych, które w głównej mierze stanowią troskę zarządów kopalń czynnych, jest rezultatem realizowania wcześniejszych planów

restrukturyzacji górnictwa, a wszelkie zmiany tego stanu wymagają udokumentowania hydrogeologicznego i oceny zagrożenia wodnego. Wpływ zbiorników o pojemnościach liczonych w milionach m^3 wody na górotwór ma duże znaczenie dla gospodarki złożem, bezpieczeństwa, sposobu i wydajności odwadniania oraz zabezpieczania się przed zagrożeniem wodnym w obrębie kopalń czynnych.

W warunkach funkcjonowania współczesnego górnictwa źródła zagrożeń wodnych, jakimi są zbiorniki wodne w zrobach, stanowią jeden z sześciu typów głównych źródeł zagrożenia, a zarazem największy problem i największe zagrożenie dla czynnych wyrobisk górniczych. W najbliższych latach, a także w długiej perspektywie, należy się spodziewać zdecydowanego wzrostu znaczenia dołowych zbiorników wodnych w kształtowaniu rozwoju zagrożeń wodnych. Pośród kierunków rozwoju zagrożeń, wraz z tendencją powiększania pojemności zbiorników wodnych w kopalniach zlikwidowanych, należy się spodziewać wzrostu ich wpływu na warunki funkcjonowania kopalń czynnych. Wraz z ustabilizowaniem warunków hydrodynamicznych w rejonach zlikwidowanych i spiętrzeniem wody na niewielką odległość od powierzchni należy się liczyć ze wzrostem wpływu zbiorników na stan zagrożenia powszechnego (zapadliska, zalewiska, podtopienia), zwłaszcza w okresach ekstremalnych zmian warunków atmosferycznych. Docelowo zaznaczy się efekt środowiskowy zatapiania zrobów związany ze wzrostem zanieczyszczenia wód poziomów wodonośnych w nadkładzie i wód powierzchniowych przez zanieczyszczone wody dołowe.

Ponieważ następuje zmiana jakościowa kierunków, przyczyn i źródeł zagrożenia wodnego w kopalniach węgla kamiennego należy się spodziewać, że zmiany będą zmierzać głównie do pogłębienia stanu wzrostu zagrożenia ze strony kopalń zlikwidowanych. Stąd już od 2000 r. za istotne uznano w GIG skierowanie uwagi, głównie na badania metodyczne, zarówno laboratoryjne o różnej skali obserwacji w odniesieniu do właściwości skał i rumoszy skalnych, jak i polowe i prognostyczne wraz z zaproponowaniem wielokierunkowej aplikacji metod do praktyki górniczej i środowiskowej. Efektem tych prac było opracowanie i opatentowanie metody nasycania kapilarnego skał zwięzłych (Rys. 4), opracowanie sposobu oznaczania wodochłonności rumoszy skalnych i początkowej wartości współczynnika pojemności wodnej zrobów (Rys. 6), a także aparatu do badania przepuszczalności i ściśliwości oraz zmian pojemności rumoszy skalnych pod wpływem zróżnicowanego ciśnienia pionowego (Rys. 7). Podjęto także prace nad znalezieniem sposobu określenia warunków i bezpiecznych odległości eksploatacji górniczej planowanej w trudnych warunkach górniczych i przy istnieniu innych niż oczekiwane szerokości filara bezpieczeństwa. Dla takich warunków opracowano sposób wyznaczania tzw. stref bezpieczeństwa. Do ich opracowania wykorzystano metody wyznaczania filarów bezpieczeństwa oraz metody oceny zasięgu rozpraszania wpływów głównych od eksploatacji górniczej (Rys. 5). Efektem prac prowadzonych w okresie ostatnich kilkunastu lat było zaproponowanie zmian w definiowaniu zagrożenia wodnego, klasyfikowaniu stanu tego zagrożenia oraz jego źródeł. Zaproponowano też klasyfikacje: dołowych zbiorników wodnych, złóż położonych w pobliżu zbiorników w zlikwidowanych kopalniach oraz bezpieczeństwa wodnego wyrobisk szybowych. Opracowane metody badań i oceny mają szerokie zastosowanie praktyczne nie tylko w ocenie zagrożenia wodnego i ograniczaniu tego zagrożenia, ale także w ocenie zasobów wody w zbiornikach kopalń zlikwidowanych i ocenie energii z tych wód oraz zasobów metanu wolnego w opuszczonych zrobach i wyrobiskach górniczych. Ich zastosowanie w hydrogeologii ma istotne znaczenie w ocenie i szacowaniu zasobów wód w wodonoścach zbudowanych z porowatych zwięzłych ośrodków skalnych. Ma także duże znaczenie i zastosowanie w inżynierii środowiska w szacowaniu zasobów wód, ocenie warunków gromadzenia i warunków ich przepływu oraz migracji zanieczyszczeń głównie w obrębie zbiorników wodnych na powierzchni zrekultywowanych przez zasypanie skałą płonną. Wyniki badań z proponowanych metod badań laboratoryjnych mogą posłużyć do oceny zmienności warunków filtracji w obrębie brył zwałowisk zbudowanych z materiałów mineralnych np. skał płonnych, a tym samym do budowy modeli hydrogeologicznych i modeli migracji zanieczyszczeń. Proponowany zakres badań i możliwości ich wykorzystania i zastosowania ich wyników, w sposób wyraźny może poprawić dokładność ocen, prognoz i modeli środowiskowych i hydrogeologicznych w obszarach działalności górnictwa głębinowego i odkrywkowego.

Słowa kluczowe: zagrożenia wodne, restrukturyzacja kopalń węgla kamiennego, hydrogeologiczne właściwości skal i górotworu, metody badań, Górnośląskie Zagłębie Węglowe

1. Introduction

Water hazard in underground mining occurs when mining works go below water table of the first aquifer. Initially the steps limiting the threat were aimed at developing techniques and methods which increase efficiency of dewatering mine workings and the rock mass. Nowadays such methods as: freezing and cementation of the rock mass around mine workings, barriers against inflows, waterproof plugs, drainage holes, and finally more and more efficient drainage systems including submersible pumps, are standard methods to fight water hazard. However, to plan mining works and technical facilities properly to prevent the hazard, at each stage of mining operations a coal mine requires evaluating hydrogeological conditions including evaluation of water hazard. Through *water hazard to mines* is meant a *possibility of an inrush or uncontrolled water inflow (brine, lye) or water mixed with loose material into mine workings and into the fracture zone around them, posing a threat for mining operations or personnel of a mine* (hydrogeological dictionary Dowgiałło et al., edit., 2002).

The demand for fuels in the interwar period resulted from the economic situation of the state and its geopolitical situation. It determined directions and intensity of mining activities. Mining activities of the interwar period were slowly intensified, which was directly linked with the recovering industry and its demand for coal, as well as the situation on the market. During the war and after 1945 intensification of mining activities was commanded. Production of coal in the interwar period reached the level of 27-46 million ton per year, in 1945 it was approx. 25 million ton and in 1979 – 201 million ton of coal. Development of underground mining, which resulted in a rapid increase in production, caused an increase in the influence of mining on the rock mass, intensity and range of drainage of the rock mass (Różkowski, 2003) and the volume of water inflow in mine workings (Wilk edit., 2003). Changes in mining industry influenced the state and formation of water hazards in the course of time, and perception of the hazard itself.

Evaluation of water hazard is a forecast of possibility of its occurrence from the sources in workings, in the rock mass, or on the surface. It usually contains evaluation of its course and consequences as well as capabilities of mines to defend against it and prevent it. Technical capabilities of preventing the hazard are determined by mining situation and natural conditions, together with current economic performance of mining companies. Since 1989 economic conditions of mine functioning are tightly linked with the conditions and rules of market economy (especially international market of energy), the state's energy policy and the condition of the state's economy. On one hand in the forecasts until 2030, made in recent years, an increase in demand for fuels, including coal (Dubiński, 2013), is expected. Yet, on the other hand, it is indicated that restructuring of Polish coal mining industry is necessary. As a result of every so-called restructuring of mining activities, a certain number of mining companies was closed, merged, or split. From the perspective of water hazard evaluation as a result of realisation of previous plans of restructuring mining industry, conducted mainly in the 1990s, in the vicinity of active mines and prospective mining areas, there are closed coal mines which are more and more often partially or completely flooded. Reservoirs of the flooded mines change natural conditions in their surrounding and force active coal mines to implement changes to their planned and conducted mining activities.

2. Certain natural conditions of water hazards occurring in coal mines of Upper Silesian Coal Basin (USCB)

Water hazards in underground mines are determined by geological and hydrogeological conditions of deposits. From the point of view of forming water inflows into mine workings the character of formations covering productive carboniferous series and differences in physical and mechanical conditions of the surrounding of mine workings play the crucial roles (Fig. 1).

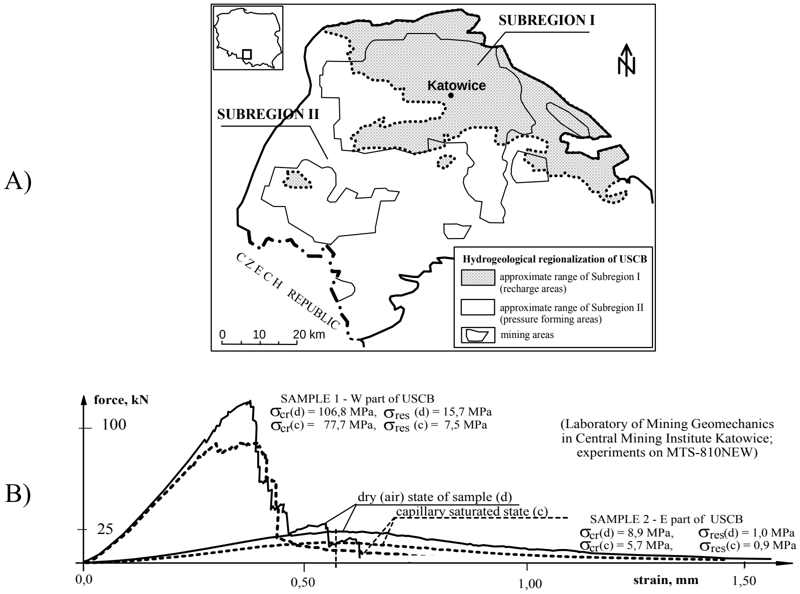


Fig. 1. A) Hydrogeological subregions in USCB (Różkowski, 2003) and B) differences in physical and mechanical properties of formations of various lithostratigraphic series from different areas of USCB considering different states of rock saturation with water (acc. Haładus et al., 2005)

There are between a few and several distinguishable hydrogeological regions, which are situated within so-called hydrogeological subregions, i.e. a hydrogeologically outcropped area (subregion I) and a hydrogeologically covered area (subregion II, Różkowski, 2003). Location of coal mines within a given hydrogeological subregion is a very important factor influencing the state of water hazards in hard coal mines. It is the factor which is mainly responsible for the volume of water inflow into mine workings and for the quality of water in coal mines of USCB. Natural inflow (yearly) into mines in 2010 was in total 657,500 m^3 daily, out of which 35% (nearly 230,000 m^3 daily) is the inflow of water pumped from closed mines. According to GIG's data, inflow into mines located in the subregion I is approx. 63% of total inflow of water into mines. Merely 10% is the water flowing into mines of subregion II. The remaining 27% of total inflow, is water flowing into mines, situated either partially in each of the subregions or within the range of hydrogeological windows i.e. discontinuities in non-permeable formation separating permeable formations in subregion II (Bukowski & Augustyniak, 2013).

The volume of water inflow into mines determines the method and efficiency of their drainage systems, which were usually built at the same time as the mines. Scale and design of the drainage systems in mines built before 1990 could not foresee neither increased water inflows from neighbouring mines being closed, nor formation of large water reservoirs of class I in the vicinity (Bukowski, 2010a). The volume of water to be removed with drainage systems of active mines is determined by natural and technical conditions and due to closure of mines and, more and more often, also by the vicinity of workings in flooded mines. Simultaneously, huge environmental costs imposed on mines for pumping and discharge of water and various potential problems assiciated with its components (eg. Winid, 2013), make them search for methods to limit salt discharge, e.g. through accumulating saline water in mine workings, which become a potential source of water hazard.

Conditions of inflow of water and state of mine workings, apart from technical and mining conditions of conducting the activities, determine geological structure and natural properties of rocks and of the rock mass surrounding coal seams. Lithologic characteristics of the surrounding of mine workings determines the amount of water occurring in the vicinity of a seam and hydrodynamic conditions. Coal mines situated among the layers of Upper Silesian and Cracow Sandstone Series, generally have high water richness and high intensity of water inflow into mine workings. Coal mines situated among coarse-grained formations of shallow Cracow Sandstone Series belong to the most waterlogged ones (Wilk edit., 2003). Faulting of a deposit in the vicinity of water reservoirs and waterlogged fault fractures and other cracks e.g. so-called Weber's voids, is an often cause of occurrence of increased inflow of water or inrushes into active mine workings (Rogoż & Posyłek, 2000). Whereas an increase in water inflow in mine workings results in changes in moisture of geological surrounding of specific values of strength-deformation parameters (Bukowska, 2005, 2013). Hence the changes in properties of rocks under influence of drainage or saturating them with water (Bukowski & Bukowska, 2008, 2012), and as a result changes in hydrogeological conditions; including conditions and directions of water flow in workings and in the rock mass as well as ability to accumulate it (Haładus et al., 2005).

Apart from changes in geomechanical conditions, rock mass rockburst and tremor hazard may have considerable influence on the possibility of occurrence of water hazard in a coal mine as well as its scale and consequences. The consequences lead to changes in properties of rocks and of the rock mass, which usually improve its hydrogeological parameters and deteriorate the parameters characterising its strength properties. It is important to consider it while dimensioning hydro-engineering structures in workings and assessing their strength as well as selecting safety factors in calculating and estimating critical dimensions of safety pillars (Konstantynowicz et al., 1974; Bukowski, 2010b). In the methodology of conducting mining works in water hazard conditions recommended in the 1970s (GIG Instruction, 1974) the situation of manifold "restructuring of mining industry" with closing and flooding a significant number of mines was not foreseen. The method of securing active mining works against water hazard was based on the 1960s' classification of sources of water hazard (Marchacz et al., 1965).

3. Sources of water hazards in today's conditions of functioning of hard coal mining in USCB

Among the sources of water hazard two main groups based on the criterion of so-called "free flow of water" were distinguished. Group I of sources of water hazard refers to the ones accumulating water of so-called "unlimited flow" and group II of sources of water hazard refers to the ones with water of so-called "limited flow". In each of the groups there are three main types of sources of water hazard (Marchacz et al., 1965; Posyłek & Rogoż, 2003), i.e.:

- in the group I among sources of water hazard were distinguished:
  - I.1. water reservoirs and watercourses on the surface,
  - I.2. water reservoirs in goafs and in mine workings,
  - sometimes a separate category is added of 1.3. water reservoirs in karst voids,
- group II of sources of water hazard consists of:
  - II.1. aquifers, water bearing strata,
  - II.2. waterlogged faults, cracks and caverns,
  - II.3. open boreholes, not liquidated or wrong liquidated boreholes.

As far as the sources of water hazard type I.1 are concerned, their evaluation depends mainly on the type of a reservoir or a watercourse (natural, artificial) as well as its volume and inflow. It is important to evaluate their connection with the natural bottom, as well as evaluation of the influence of mining activity and conditions of occurrence and susceptibility to breaking of non-permeable layers between workings and the surface. An increase in the depth where mining activities take place, on one hand separates mine workings from the surface sources of water hazard, on the other hand it results in current and previous exploitation influences overlapping and concentrating. High degree of post-mining destruction of the rock mass causes a decrease in the horizontal range of influences, yet at the same time, there is an increase in vertical consequences of mining. It can be a cause of reactivating shallow located goafs and forming uncontrolled water reservoirs in mine workings within shallow located levels of mines. The reservoirs are distinguished as sources of water hazard type I.2.

In the conditions of functioning of today's mining industry sources of water hazards of type I.2, pose the biggest threat for active mine workings. It refers to both Polish, and Czech part of Upper Silesian Coal Basin and sources of hazards formed as a result of influence of mining activities on aquifers and surface water (Grmela & Rapantova, 2003). It is a result of the fact that a reservoir can be formed in virtually any part of uncontrolled mine workings where either the floor or location of the workings disable or significantly limit flow of all the water to the nearest drainage base. Their recharging and conditions of flow as well as water accumulation usually remain beyond any control. Conditions of water flow are particularly dependant on hydrogeological conditions and geomechanical properties of the vicinity of workings and goafs and changes in them resulting from the influence of water (Haładus et al., 2005). On average, in each mine there are a few, several, or even well over a hundred reservoirs of various capacity, from just several m^3 to several million m^3 of water (Bukowski, 2010a). The reservoirs due to various scale of difficulty, they may become for mining activities, are classified according to their size (water capacity). There are three classes of reservoirs, i.e.: class I of reservoirs of capacity $V > 100{,}000$ m^3 (reservoirs mainly in the abandoned parts of mines and closed coal mines), class II of $V = 10{,}000 \div 100{,}000$ m^3 (most common) and class III of $V < 10{,}000$ m^3 of water (slight inundations of workings and technological reservoirs).

Sources of water hazard type I.3 (waterlogged karst voids), like sources of water hazards of type I.1 (reservoirs and watercourses), due to their distance from active workings generally do not pose a threat in the areas of hard coal mines in USCB which have operated there for many years. The area of occurrence of the type of sources of hazard is, in general, limited to the area where formations susceptible to karst phenomena (e.g. carbonate formations) occur. Flooded karst voids of smaller size and range may occur also in gypsiferous Triassic series in the overburden of productive carboniferous deposit series in other areas of USCB. In the current situation of hard coal mining, karst voids may be important sources of hazard mainly for shafts and newly-started mining activity.

In group II of sources of water hazard there are the types of sources of hazard, which are considered to be less dangerous. In spite of that there are significant qualitative differences among them.

Aquifers as sources of water hazards (type II.1.) are generally less important for active mines, situated within a regional cone of depression, than for the mines under construction or planned to be built in reserve areas, outside the cone of depression. In old mining regions, coal mines reach for deeper and deeper coal deposits, which separates their mine workings from shallow highly rechargeable water rich aquifers. Only in the areas of high concentration of influences of mining activities within the hydrogeologically outcropped area (subregion I), the scope and range of drainage caused by destruction of the rock mass is so extensive that originally water rich aquifers do not retain water any more. Generally in USCB there is a dependence of lowering hydrogeological parameters of rocks, their water absorption and water richness and recharge of water on the depth, and parameters describing deformability of the rocks. The tendency is negative as far as an increase in salinity of water and strength parameters of rocks are concerned (Rogoż & Posyłek, 2000; Wilk (ed.), 2003; Różkowski, 2003; Bukowska, 2005). Hence, it is commonly believed that aquifers in carboniferous formations with increasing depth lose their significance and their contribution to an increase in water inflow into mines is little. In mines situated in subregion II, as well as among water rich formations of Cracow Sandstone Series and mines planned to be built outside the regional cone of depression, they are important for safety of mining safety. Their huge significance within the area of subregion II is a consequence of the fact that the younger aquifers (Quaternary, Miocene), often demonstrate quick condition, and the threat they pose to shafts of the mines located there (Bukowski, 2011).

Sources of water hazard type II.2. – waterlogged faults, cracks and caverns, are sources of hazard of high qualitative diversity. Their importance depends on the size of fault fractures, Weber's voids and caverns, and on conditions of recharging with water. Evaluating them, critical distance between mine workings and sources of hazard plays an important role. Fault fractures which are not filled with rock material or filled with material which can get liquefied when the hydrodynamic balance is disturbed in the area of a fault, are the most important and the most problematic for mining operations. It refers mainly to mining activities conducted in the vicinity of faults of the water rich Cracow Sandstone Series. Formations of the series, consisting in over 80-90% of unconsolidated sandstones, have high values of hydrogeological parameters (open porosity, permeability and drainage capacity), with high deformability and, for USCB rocks, low or very low values of strength parameters, especially when they are saturated with water (Fig. 1). Hence for the mines operating among formations of the series, faults are the fundamental hindrance in planning exploitation and dewatering of mine workings and the rock mass. It refers particularly to the conditions, in which they are a link between highly waterlogged layers of carboniferous series or the overburden of a deposit and mine workings. In the initial phase water inflow in them is usually very high with effects in mine workings, and often on the surface in form of subsidence (Rogoż & Posyłek, 2000).

Fault fractures located among older formations of Mudstone Series, Upper Silesian Sandstone Series and Paralic Series may play an important role in transporting water from water reservoirs into goafs of e.g. mines which are flooded in the vicinity. Faults can play there an important role in evaluating water hazard especially, when within the working life of mines they were subjected to influences of mining operations and tensile stresses. Cracks and caverns in form of e.g. Weber's voids are an often source of inrush hazard, yet, more often of increased inflow of water discharged into the voids from neighbouring layers of waterlogged sandstone. Generally today's technical protection measures of mines enable fighting the threat of the type of sources successfully.

In today's reality of mine functioning, due to small volume of accumulated water, sources of water hazard type II.3. (open boreholes) are less important. Yet their significance increases when they are not treated as just a source of hazard, but as a hydraulic link between mine workings and the source of water hazard (an aquifer, a fault, a water reservoir being formed, etc.).

The description of the sources of water hazard presented above was verified due to properties and behaviour of rocks in various conditions of water inflow. The modification questions certain criteria of evaluation of today's most dangerous sources of water hazard i.e. water reservoirs in mine workings. It is indicated that it is necessary to consider differentiation of geomechanical properties of rocks and of the rock mass itself. Occurrence of water of different freedom of flow within one reservoir is also pointed out (Fig. 2).

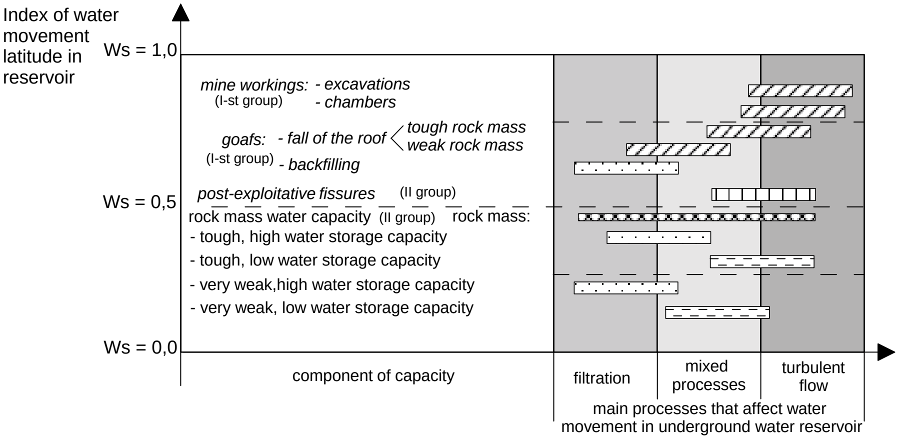


Fig. 2. Schematics of the share of processes determining flow of water within an underground reservoir and their influence on volumetric composition of a reservoir (acc. Bukowski, 2010a)

In the proposed classification of the sources of water hazard not two but three groups of sources of hazard are distinguished and an encore change in nomenclature describing freedom of water flow is proposed. Basing on the analysis we carried out and expertise in evaluating sources of hazard acquired in the last few years distinguishing three of sources of water hazard is proposed, namely (Haładus et al., 2005):

- **I group of sources of water hazard** accumulating water of *very high freedom of flow*, in the vicinity of the strong rock mass in the state of capillary saturation (*nk*) and with low susceptibility to water (uniaxial strength (*nk*) >> pressure of the rock mass P_H, and residual strength (*nk*) ≈ value of pressure of the rock mass P_H),
- **II group of sources of water hazard** accumulating water of *high freedom of flow*, in the vicinity of the rock mass of medium strength in the state of capillary saturation and susceptible to water (uniaxial strength (*nk*) ≥ P_H, residual strength (*nk*) ≥ 50% P_H),

- **III group of sources of water hazard** accumulating water of *low freedom of flow* in the vicinity of the weak rock mass in the state of capillary saturation (uniaxial strength (*nk*) << P_H, residual strength (*nk*) << 50% P_H) and highly susceptible to water .

Nowadays it is believed that apart from the ones already pointed, according to criteria of Haładus et al. (2005), group I ought to include the following types of sources of water hazard:

- I.A. water reservoirs and watercourses on the surface, including post-exploitation overflow lands reclaimed with waste rock,
- I.B. water reservoirs in roadways and goafs (mainly caving ones) in the vicinity of the rock mass of medium and high values of strength parameters and low deformability and susceptibility to water, immune to processes of getting soggy, scouring and reconsolidation,
- I.C. waterlogged karst voids in the overburden and waterlogged fault fractures of Cracow Sandstone Series and older series among the formations of medium and high strength with observed or presumed lack of filling with the rock material, including fault fractures linking aquifers and possible water reservoirs in goafs,

Group II shall contain the following types of sources of water hazard:

- II.A. water reservoirs in goafs in the vicinity of the rock mass of medium values of hydrogeological and strength parameters of the rock mass and medium susceptibility to water, of low susceptibility to processes of getting soggy, scouring and reconsolidation, water reservoirs in caving goafs as above filled with mixtures of water and fine grain materials,
- II.B. waterlogged aquifers of high hydrogeological parameters, water rich and of facilitated water recharge, and quick condition type aquifers (for example: quicksand),
- II.C. boreholes of unknown state and accuracy of closing, especially the large diameter ones, linking mine workings with sources of water hazard group I and group II,

Group III shall include the following types of sources of water hazard, of generally small capacity and poor water recharge:

- III.A. water reservoirs in goafs in the vicinity of the rock mass of low strength values of the rock mass, of high susceptibility to water, to getting soggy and scouring, easy to reconsolidate, and of low values of hydrogeological parameters and low recharge,
- III.B. water low aquifers of low values of hydrogeological parameters, or dewatered as a result of drainage,
- III.C. open small diameter boreholes of unknown state, in the vicinity of the rock mass susceptible to deformation which leads to limiting the flow of water, especially the boreholes linking workings with the sources of water hazard of group III.

Water hazard for the surface of mining areas is still a subject of discussion and research, e.g. into developing a hydromorphologic method of evaluating water hazard for the surface of mining areas (Ignacy, 2010). So far only evaluation of water hazard on the surface from reservoirs and hydro-engineering structures has been devised and classified (Posyłek & Rogoż 2003).

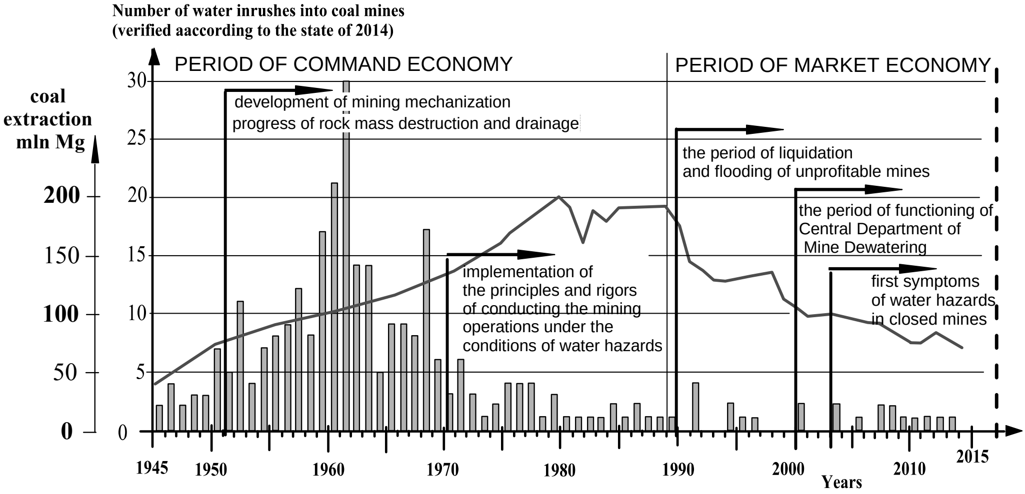
4. Influence of changes in functioning of mining industry on shaping water hazards

Among the changes in functioning of mining industry after 1945 two main stages can be distinguished: the first one (1945-1989), associated inseparably with command economy and tendency to increase constantly the volume of production and the second one (1990-now), associated with market economy and a few-fold increase in emphasis on changes in mining industry aimed at restructuring it. In both periods there was a change in expectations towards hard coal mining industry, followed by various adaptation actions, including technical ones, legal and economic changes. The processes of the transformations affect significantly the course of mining activities, requirements and possibility of evaluating water hazards in underground mining companies (Bukowski, 2013).

A good example of changes in the way coal mining industry in Poland and evaluation of water hazards are treated, are frequent changes in implementing provisions of mining law which have taken place in the last 20 years. The introduced changes, especially the ones referring to defining and evaluating water hazard as well as the position of the evaluation of the hazard in deposits documentation have been a frequent subject of discussion. A positive direction of future changes is the proposal to simplify categories of natural hazards in mining, including water hazard. Since 2013 a bistate system is proposed, which includes water hazards in category "0" – no hazard, and in category "1" – occurrence of hazard. The state of occurrence of hazard can be bistate again: occurrence of hazard (category 1a) and state of significant hazard (category 1b) (Bukowski et al., 2013).

Generally, in spite of imperfection of the criterion, frequency of water (or water with loose material) inrushes into workings (so-called: inrushes) is assumed to be a measure of water hazard. Imperfection of the criterion lies in the fact that in different periods water hazard was defined differently and it results from technical development in fighting the hazard. A water inrush from the 1970s, according to today's standards of mining, can be treated as a relatively easy to fight so-called increased water inflow. Analyses of hitherto experience show (Fig. 3), that the trend to concentrate production, started in the 1950s, and the start of coal production with use of longwall coal cutters (1960s) collates with an increase in the number of symptoms of water hazard. Together with a significant increase in the number of coal cutters and an increase in the number of mechanised longwalls, from 112 in 1960 to 519 in 1970 (Trojnar & Drainert, 1999), came the most serious consequences of the intensified rock mass destruction processes.

In 1950-1970 together with the processes of destruction of the rock mass and connecting mines with workings and zones of overlapping influences, the regional cone of depression in USCB starts forming. Increase in the intensity of drainage initially resulted in an increase in the number of symptoms of water hazard up to 30 inrushes in 1961, and then there were significant fluctuations in the number of inrushes, yet still the number was high. Further development of mechanization and common use of the next generation of coal cutters in Poland and powered roof supports in 1970-1980 led to a significant increase in production and mining advance rate, while reducing the number of longwalls from 991 in 1970 to 731 in 1980. Simultaneously mining with roof rocks caving became more common (increase in the number of caving longwalls from 400 in 1970 to 495 in 1980) reducing the number of longwalls with hydraulic stowing from 504 in 1970 to 218 in 1980 (Trojnar & Drainert, 1999). It resulted in increased destruction and even higher intensity of drainage of the rock mass, which has already been partially



Source of hazards	Number of water inrushes since 1997	Incidents after1997 connected with mine closure
1.1. Reservoirs and rivers on surface	0	- 2 incidents connected with uncontrolled water reservoirs in goafs
1.2. Reservoirs in mine workings and goafs	3	
2.1. Water bearing strata	0	
2.2. Faults, fractures, caverns	5	
2.3. No isolated boreholes	0	- 4 incidents connected with uncontrolled change in water flow direction (high intensity)
3.1. Other (failure in shafts)	2	
SUM:	10	
3.2. Changing the flow direction of significant amount of water	4	???

Fig. 3. Frequency of water inrushes into Polish hard coal mines of USCB in 1945-2014 compared with the volume of production and restructuring

drained. As a result of that, after 1970 there was a significant decrease in the number of inrushes into active mine workings, which until 1990 were observed every year. After 1972 the number of events did not exceed four inrushes per year. It is also the period of intensive improvement in the method of evaluating water hazard, increase in the importance of mining supervision and the role of geological services in identifying and fighting water hazard as well as introducing regimes and regulations concerning mining works in hazardous conditions. The final period of command economy in mining (1980-1990), observed a decrease in concentration of production and an increase in mechanization of longwalls.

The era of market economy in Poland (after 1990) is the period of decrease in coal production (Turek, 2007) and in all indicators of concentration of production (Dubiński red., 1999). It was concluded that concentrating production is benevolent for concentrating drainage in a particular section of deposits and distribution of reservoirs in mine workings (Rogoż, 1999). The problem of filling up goafs with water from the surface and formations located close to the surface, associated with overlapping influences of mining activities and concentration of production, was not considered as a factor of an increase in water hazard. In the period nobody linked the influence of closing and flooding nearly half of hard coal mines out of 68 mines in USCB with a significant decrease in the number of inrushes. Between 1991-2006, inrushes into active mine workings were observed only in five of the years. As it can be seen in Fig. 3, lowering frequency of inrushes was not a consequence of concentrating production, but of closing a significant number of mines, where water hazard occurred.

Years after 2000 mean a new quality in evaluating water hazard in Polish hard coal mines in form of an increase in the number of underground water reservoirs of capacity estimated to be millions m^3 of accumulated water. The reservoirs classified as so-called large ones, are sources of hazard of nearly unprecedented scale. They significantly affect hydrogeological conditions and properties of rocks forming the rock mass in the surrounding, and thus the conditions of functioning of neighbouring active mines (Szczepański, 2011). Safe conditions are maintained with an organized system of stationary and submersible pumps in closed coal mines (Szczepański, 1998).

A new quality in evaluating water hazard is the fact that mining activities in old mining areas reach deeper and deeper coal deposits, located in the vicinity of the less and less watered rock mass, which does not require such extensive technical facilities for dewatering. There is a risk that as water inflow decreases with the depth of mines, their pumps will be less and less efficient and in case of emergency will be inadequate to fight the possible hazard.

Changes taking place in the quality of events which lead to occurrence of water hazard in recent years are confirmed by the fact that since 2000 there have been threats to the stationary drainage system and submersible drainage systems located in closed coal mines serviced by Central Department of Mine Dewatering in Czeladź (CZOK), created only to dewater coal mines (Szczepański, 1998). In general, possibility of occurrence of water hazard in the conditions of today's mining, closing and dewatering redundant workings is associated with geomechanical processes (roof caving and convergence in workings) occurring under influence of water in the rock mass surrounding closed mine workings. Changes in directions of water flow resulting from the processes cause further processes of uncontrollable destruction in other parts of the rock mass and unexpected accumulation of water in areas which have not been considered yet as areas of forming sources of water hazard. A side effect of the changes in the water flow may be a change in quality and chemical composition of water which flows into the dewatered area and a decrease in efficiency of submersible drainage systems. Geomechanical and hydrogeological processes, especially the ones of after 2003, caused changes in the direction of water flow (of a few m^3/minute) from the closed areas, where they jeopardised safe transfer of water into the areas where active and closed mines are located close to each other. The changes were a result of blocking routes of free water flow, considered fail-safe in previous plans of restructuring and closing mines. The processes were observed mainly within the mine workings of closed mines, located in hydrogeologically outcropped part of USCB, which remain beyond any control.

Clear examples of qualitative changes in evaluating water hazard in recent years are two within one week cases of water inrush into active workings of CZOK stationary drainage system in a closed coal mine (2010). The event was caused by, first uncontrolled formation of a reservoir of large capacity and pressure in goafs due to water flow, and then breaking the insulation between the reservoir and an available level used for dewatering. One of stationary pump systems was flooded, which forced taking sudden, costly actions to secure the area.

In another of CZOK areas, a leak of water from behind the barrier protecting one of levels of a closed coal mine from the shaft with deep-well pumps (submersible system), resulted in the state of permanent hazard, which has lasted since mid 2012 till now (April 2015). A reservoir formed in an uncontrollable way behind the barrier at pump shaft, is an threat to the submersible pump system (so far it has been considered to be impossible), which protects an active hard coal mine in the vicinity. The hazard also forced costly actions to eliminate it.

The above mentioned examples of qualitative changes in water hazards in contemporary mining industry indicate that it is necessary to verify water hazard, its sources and evaluation of the state. As it is shown in Figure 3, the number of water hazard events has not decreased in the last 10 years. Moreover it has increased when compared with the period of 1991-2006. Among the events there is also an apparent rising trend in the number of hazards of more and more serious consequences – mainly economic ones.

The role of geomechanical factor in evaluating sources of and the state of water hazard is more and more significant in its influence on hydrogeological conditions. Influence of water on caving goafs may be important for the processes of leaching pollution in the process of dewatering, and the processes of slow loss of capacity by water reservoirs within goafs subjected to cyclic changes in water inflow in the conditions of submersible drainage. Influence of water and weakened rocks and caving rock debris in the area of water table fluctuations leads to the loss of water retention capacity by a reservoir and its elements located in the conditions fluctuating water table and as a result zones of changes in the properties of the rock mass (Bukowski, 2002, 2010a). Basing on hitherto observations of processes of flooding mines and changeability of the properties of rocks under influence of water, it is believed, that the geomechanical factor shall be one of the main factors analysed in hydrogeological documentation of mines to be closed.

In the next several years, and in the further perspective, increasing significance of coal in managing energy shall be expected, together with an increase in significance of sustainable mining activity and mineral resources management (Dubiński, 2013), as well as increase in natural hazards in Polish coal mines. Hence it ought to be expected that an increase in importance of underground water reservoirs, formed as a side effect of conducted mining activities, in shaping water hazards in coal mines will be apparent. As water reservoirs in closed coal mines tend to be more and more numerous and their capacity tends to increase, an increase in their influence on the conditions of functioning of active mines is to be expected. Stabilization of hydrodynamic conditions in closed areas and piling up water to a short distance from the surface causes loss of water retention capacity of the rock mass and an increase in the influence of reservoirs on the state of public hazard (subsidence, overflow, flooding), especially during extreme changes in weather conditions. The eventual environmental effect of flooding mines in USCB, is associated with an increase in pollution of water of aquifers in the overburden and surface water.

It is foreseen that identifying, characterising and classifying underground water reservoirs treated as sources of water hazard and reservoirs of water of very high freedom of flow (group I) will play a significant role in water hazard evaluation. The main element of the hazard evaluation will be estimating and characterising the volume of a reservoir, evaluating quality of water it accumulates and influence of the reservoir on the rock mass and mine workings in its surrounding.

Increase in water hazards from underground water reservoirs requires better and better research methods. Nowadays efficient methods of evaluating water reservoirs formed as an effect of sealing goafs with mixtures of water and fly ash are researched into. Basing on the experience gathered in active mines, in such areas significant obstacles to conducting mining activities safely shall be expected. Goafs sealed for fire prevention purposes with water-fly ash mixtures are sources of water hazard which are unpredictable, non-homogenous and very difficult to dewater. Reservoirs created in such a way are a numerous group of sources of hazard in active mines as the method has been commonly used to prevent fires since the 1980s.

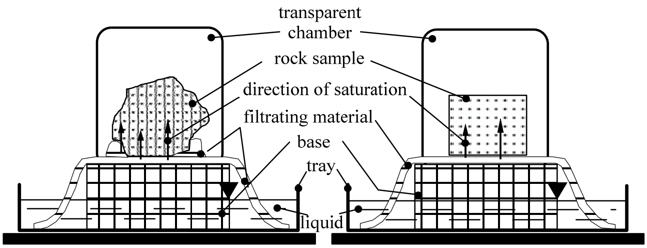
The research works into hydrogeology and mining geomechanics conducted at the Central Mining Institute are to meet the challenges. The effects of the research are a few new and modified tests methods which have been proposed in the last several years.

5. Research tools to evaluate water hazards in today's reality of functioning of mining industry

As it was shown in chapter 4, there is a qualitative change in directions, causes and sources of water hazard in hard coal mines. Hence, at the beginning of the 21st century it was decided to focus attention mainly on methodical investigations, both laboratory ones of various scale of observation of properties of rocks and rock debris, in situ ones and forecasting ones followed with a proposal of their multidirectional application in mining practice.

Since 1994 restructuring activities have been aimed mainly at closing and flooding hard coal mines. After years (since the 1970s) methodical investigations into evaluation of water hazard, and the course of the process of flooding mine workings and the rock mass surrounding them, were resumed. Research to explain influence of water storage capacity of the rock mass on the course of the process of flooding coal mines was initiated. In situ method of determining water storage capacity of the rock mass (D_{ch}, or d_{ch}), methodological principles of its determination and its practical use have been already described (Bukowski, 2002). The components of the evaluation are: water capacity of goafs, mining fissures and of the rock mass. Evaluating water capacity of the rock mass dewatered as a result of drainage and expected volume of water, which the rocks can absorb again in the process of flooding the closed coal mines, a method of determining gravitational drainage capacity of hard rock has been devised (Fig. 4).

The method employs the phenomenon of active capillarity of the rock medium to determine capillary moisture. Once having saturated the rock it enables determining content of free water



A) unregular solid rock sample B) regular solid rock sample

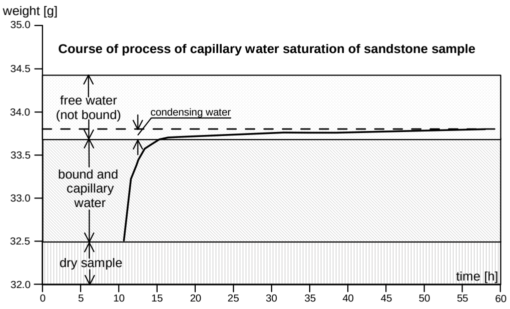


Fig. 4. Laboratory set to determine drainage capacity of rocks with the method of capillary saturation together with a sample graph of the course of the test (acc. Bukowski, 2007)

in the rock and volume of pores of over capillary dimensions. It was assumed, that as a result of feeding with water, especially the rock mass situated in the hydrogeologically outcropped area (subregion I), will not be completely dewatered. It was also assumed that in natural conditions the mean moisture of the drained rock mass will correspond with capillary moisture of rocks. It was the basis for devising the weighing method of determining gravitational drainage capacity of rocks, so-called *method of capillary saturation* (Bukowski, 2007) and applying it to obtain the state of capillary saturation of rocks in geomechanical tests. Results of the geomechanical tests of rocks in the state of capillary saturation allow authenticating calculations of strength of measures against water hazard e.g. safety pillars. Novelty of the method is possibility of measuring every kind of water in the rock, referring to natural process of draining the rock, referring to natural state of moisture of rocks and eliminating any artificial element to drain water (centrifugal force, temperature, hygroscopic material etc.) and time of its influence on a sample (applied in other test methods).

Evaluating water hazard in the areas of safety pillars it is impossible to avoid evaluating rockburst hazard, including the method employing the parameters determining rockburst susceptibility of the rock mass (Bukowska, 2012; Bukowska et al., 2012). Rockburst phenomena and high energy tremors of the rock mass disturb stability of the pillars and lower their strength. Employing the knowledge of strength and deformation properties of rocks in USCB, including post-peak failure properties (Bukowska, 2013, 2015), it is advised to select safety parameters individually to calculate width of safety pillars on the side of reservoirs of closed mines and other underground reservoirs. Safety coefficient, which on average increases by 1.5-2.0 times the width of pillars if high rockburst or tremor susceptibility of the rock mass is concluded, is considered to be safe (Bukowski, 2010b).

Bearing in mind how difficult it is to evaluate real hazard in many inaccessible areas, to support dimensioning safety pillars, a method was devised to determine areas of water hazard (Fig. 5) (Bukowski, 2009). The method employs already known ways of determining width of safety pillars parallel to the bedding (Konstantynowicz et al. 1974) and, used in mine surveying, assessment of deformation of the rock mass and the surface with determination of the range of dissipating main influences of mining activities (Kowalski, 1985).

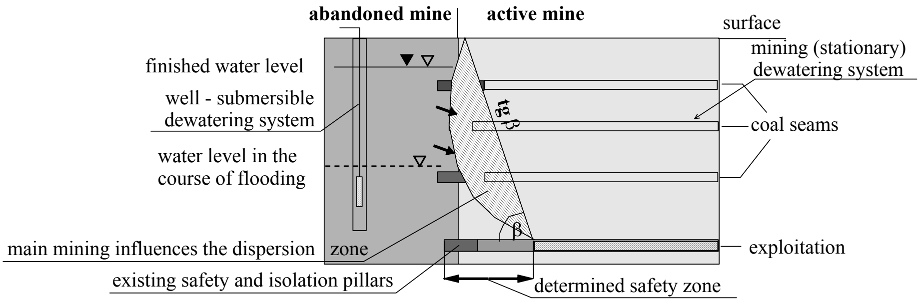


Fig. 5. Schematics of determining a safety zone (acc. Bukowski, 2009)

Analytical studies of calculating the range of main mining influences and width of the safety pillar, may be useful in determining safety zones in areas where dimensions of safety pillars have been already determined. It refers particularly to border areas and parts of deposits located in the vicinity of water reservoirs in coal mines which are being closed.

In the light of events and symptoms of water hazard w goafs and shafts in the last several years it was decided to start research into evaluating water absorption, compressibility and permeability of rock debris. To measure water absorption a stand was devised for physical and mechanical tests (Fig. 6) of rock samples of between several and a few dozen kilograms, of known grain size distribution and petrographic composition. Having followed the right procedures, soaking in water and then draining, the samples were tested. With the tests water capacity of caving goafs in the pile state – without vertical pressure, was evaluated. The results were referred to so-called fresh caving goafs, their capacity and initial value of water capacity of goafs (Bukowski, 2004).

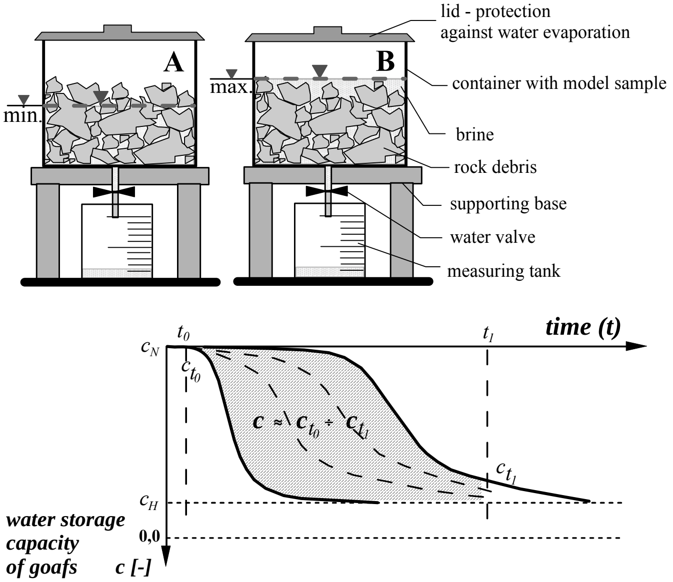


Fig. 6. Schematics of a site to measure water absorption of rock debris and initial value of water capacity of goafs *c* (acc. Bukowski, 2004)

Conducting the tests it was concluded, that the method of evaluating water absorption can be also applied in environmental studies to determine capacity of a pile formed of carboniferous waste rock. It is an important issue as waste rock, since the 1970, has been commonly applied to reclaim overflowed areas and morphological subsidence created as a result of post-mining subsidence. With support of hydro morphological methods of evaluating the surface, laboratory tests of rock debris enable determining the volume of water accumulated in the areas of reclaimed overflowed area and characterise the area of former overflowed area as a source of water hazard.

Apart from model methods employed to evaluate conditions around mine shafts (Bock, 2014) an important element of evaluating the threat is a possibility to get data in tests conducted with oedometr type apparatus (Fig. 7) devised by Bromek and Bukowski (2002).

The device is used in measurements of compressibility and permeability of materials used in backfilling unnecessary shafts (Bukowski & Niedbalska 2013; Prusek et al., 2014). The method

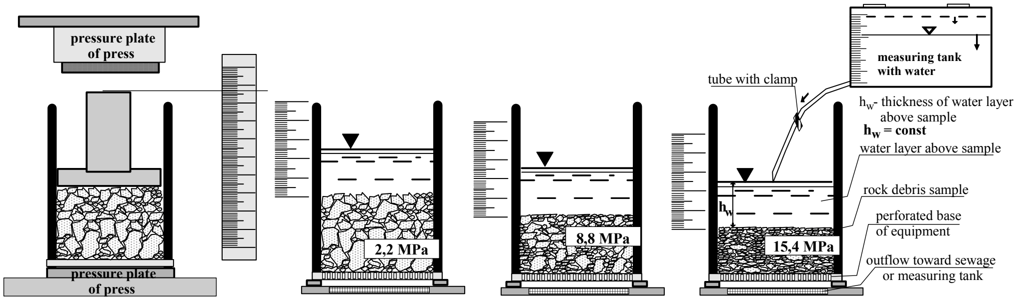


Fig. 7. Device to measure permeability, compressibility and changes in capacity of rock debris under different values of vertical pressure (acc. Bromek & Bukowski, 2002)

based on so-called Kamieński's pipe may be successfully used to evaluate permeability of caving rock debris and thus to evaluate water hazard associated with the flow - filtration of water through goafs. It may be also used to evaluate changes in water and methane capacity of caving goafs depending on the pressure of overburden rocks, measured with the depth of goafs below the surface. Application of the method to determine methane content in goafs of both non-flooded and flooded workings of closed mines can be substituted with tests of desorption of methane from coal into the space filled with water under increasing pressure of water in a reservoir which is being formed (Krause & Pokryszka, 2013). The method can be successfully applied to evaluate conditions of filtration of rocks and mineral materials used in reclaiming open cast workings and on dumps. Evaluation of conditions of water filtration with the research method enables building a credible numerical model of a dump watered with underground water. The basic aim of devising and applying the method was evaluating water filtration through backfills of closed shafts of high water inflow and using it evaluate water hazard associated with closing shafts (Bromek & Bukowski, 2002; Bukowski, 2011).

The effect of conducted works and experience associated with evaluation of water hazard in changing realities of hard coal mining in USCB, apart from classification of sources of water hazard (Chapter 4), were proposed amendments to the definition and classification of the state of water hazard (Bukowski et al., 2013) and classifications, including: underground water reservoirs, deposits in the vicinity of reservoirs in closed coal mines and water safety of shafts (Bukowski, 2010a, 2011).

It is foreseen that in further tests and evaluation of water hazard it will be necessary to verify opinions concerning the diminishing role of water hazard in evaluation of mining activity conditions. Changes in the structure of water hazards in coal mines in recent years stimulate further search for better test methods, evaluations and forecasts. Further improvement in the quality of evaluation of hydrogeological conditions, including: water hazards in Polish hard coal mines, apart from the ones mentioned above, can be made e.g. through improving organizational actions and legal regulations (Bukowski, 2013).

6. Summary and conclusions

Evaluation of water hazard in hard coal mines is a continuous process, which has to follow changing conditions of functioning of mining industry. Hence, it was considered that for forecasting water hazards it was important to analyse hitherto events and certain conditions of occurrence of water hazards, to identify properly sources of water hazard and conditions which enable its occurrence. It allowed intensifying in recent years works on research tools, which would be dedicated for evaluation of water hazards. Hence new research methods of wide applicability in mining and environmental engineering modified or developed at GIG. They serve to provide a better description and characteristics of sources of water hazard in today's conditions of functioning of hard coal mining in USCB. Basing on the analysis of changes in functioning of hard coal mining and events showing symptoms of the hazard after 1945 it was concluded that:

Changes in functioning of mining industry influence significantly emergence and evaluation of water hazards, and they are a factor enforcing search for better solutions, research and evaluation methods. The effects were:

Radical reduction in the number of inrushes into coal mines in USCB in the period when numerous mines were closed after 1990, as a result of so-called restructuring of mining industry.

Renewed increase in the number of dangerous events caused by changes in hydrogeological conditions after closing mines and flooding part of their workings up to pre-determined level.

A qualitative change in evaluation of water hazard associated with new and hitherto unclassified, causes of hazard, including: occurrence of water hazard in the areas of closed mines and for their stationary and submercible drainage systems.

The consequence of changes in functioning of mining industry and changes in conditions of occurrence of water hazard was developing both modified and new methods of laboratory tests of rocks and rock debris, methods of evaluating water resistance of pillars and safety zones, and verifying old classifications of hazards and devising classifications of new ones with their sources.

The developed research and evaluation methods have various practical applications including: evaluation of water hazard and limiting it, estimations of the volume of water in reservoirs of closed mines and estimating energy of the water and free methane deposit in abandoned goafs and mine workings. Applying them in hydrogeology and environmental engineering can significantly improve accuracy of the estimations, forecasts, as well as environmental and hydrogeological models.

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