WATER CAPACITY OF ABANDONED WORKINGS IN UNDERGROUND COAL MINES

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ABSTRACT : The quantity of water being held in old workings may be calculated by multiplying the volume of mined out coal bed by the water capacity coefficient. On the basis of investigations carried out in mines and in laboratories equations were established, that enabled to determine the mean values of water capacity coefficient depending on the mining method used, depth at which old workings are situated, or rock pressure and on the quality of material used for stowing the old workings.

RESUME : La quantité d'eau contenue dans les vieux travaux miniers peut être calculée comme le volume de la couche déhouillée multiplié par le coefficient de la capacité en eau dans les vieux travaux. A la base des recherches effectuées in situ et en laboratoire, on présente les équations permettant de déterminer les valeurs moyennes du coefficient de la capacité en eau dans les vieux travaux en fonction de la méthode d'exploitation, profondeur de la couche ou pression des terrains et qualité du matériau de remblayage.

RESUMEN : La cantidad de agua almacenada en las antiguas labores mineras, se puede calcular multiplicando el volumen de la capa de carbón por un coeficiente de capacidad de agua en los trabajos. Basándose en las investigaciones ejecutadas in situ y en laboratorio, se han establecido ecuaciones, que permiten determinar valores medios del coeficiente de capacidad de agua en los trabajos, en función del sistema de explotación empleado, profundidad a la que se localizan los viejos trabajos, presión de la roca y calidad del relleno.

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1. Introduction

In underground coal mines there is a lot of water reservoirs in parts of old workings having no gravitational outlets, whose capacity reach hundreds of thousends of cubic meters. They represent the serious hazard of mining work carried out in their proximity, because, in some circumstances, they cause the risk of water inrush into active workings. The only reliable way to eliminate this water hazard is the dewatering of old workings by letting off the water by gravity or by pumping it out.

In order to designe and to carry into effect dewatering of old workings, it is necessary to know, besides the general mining conditions, the quantity of water being held in the reservoir. This quantity is equal to the water capacity of flooded workings, it means to the total volume of all voids in workings that may be or are filled with free water. The water capacity of workings is always lesser than the volume of coal bed mined out in consequence of their convergence under the weight of the subsiding rock massive. The relation of water capacity of old workings V_z to the volume of extracted coal bed V_p is called water capacity coefficient c

$$c = \frac{V_z}{V_p} \qquad /1/$$

The water capacity of old workings may be then expressed as

$$V_z = c\ V_p = c\ \frac{A\ M}{\cos \alpha} \qquad /2/$$

where: A - area of the flooded workings in horisontal projection,
M - the thickness of extracted coal bed,
α - inclination angle of coal bed.

The variables appearing in the formula /2/, except the water capacity coefficient, may be read from the mine map or be calculated with known methods, therefore they do not require any closer discussion. The problem is to establish the water capacity coefficient c, that can not be determined from the mine map. Its value depends on several factors contributing to the local geological and mining conditions, from which the most important seem to be:

- method of filling old workings,
- degree of convergence of old workings.

The method of filling old workings depends on mining method and roof control used, whereas the degree of their convergence depends on the depth at which old workings are situated and on the time. There is no doubt that the process of roof breaking as well as the increase in rock pressure in workings depend, less or more, on geological conditions and particularly on the lithology of roof rocks and inclination angle of the coal bed. In this paper the approximated values of water capacity coefficient of old workings are determined depending on the mining method and roof control used and on the depth of the coal bed or on rock pressure and the quality of stowing material when the back-filling is used. Too small a number of direct measurements of workings capacity during their dewatering in mines did not permit to take into consideration the influence of local geological conditions. In order to eliminate the time factor, only the water reservoirs in old workings were taken into account, where the process of roof fall or the roaf subsidence is practically finished.

2. Geological conditions of investigated workings

The investigations of water capacity of old workings were carried out in coal mines of the Upper Silesian Coalfield. The investigations covered the workings in coal beds belonging to Namurian B, C and Westphalian A, B, C, D.

The Namurian B and C deposits are developed in alternating layers of sandstones and mudstones with coal seams. The mudstones are grey, firm, less or more sandy. They contain spherosiderites and coalified plant debris. Sandstones form thick layers. In general, they are compact, medium-grained and coarse-grained, in some places conglomerates can be met. The part of sandstones in the vertical profile is of about 40 %.

The Westphalian A and B deposits are developed similary as those of Namurian B and C. The part of sandstones being here smaller does not exceed 25 %. The thickness of particular layers is highly variable ranging from some tens of centimeters to about 20 meters. The mudstones are similar to those of Namurian B and C. The mudstones accompanying the coal beds have sometimes ability to plastyfying in contact with water. In such cases floor heaving can be observed. The sandstones have compressive strength ranging from 20 to 30 MN/m^2. Their porosity amounts to about 15 % and Darcy's coefficient to about 10^{-8} m/s, on the average.

Westphalian C and D are developed as very thick series of sandstones, chiefly arkosic, with poor clay binder. They have high porosity, exceeding often 20 % and low compressive strength, in general lower than 10 MN/m^2. The Darcy's coefficient amounts to about 5.10^{-8} m/s, on the average. The percentage of sandstones in the profile of Westphalian C and D exceeds 80 % on the average. Particular series of sandstones are interbedded by mudstones usually accompanying the coal beds. Mudstones are similar as in Westphalian A and B.

3. Water capacity of caved gobs

In order to determine the values of water capacity coefficient, investigations of 37 water reservoirs in caved gobs were carried out in 25 coal mines. The investigations consisted in possibly exact measurement of water quantity drained from old workings during their dewatering with simultaneous control of the lowering of water table in the workings, quantity of water affluing into the workings and leakage from the waste to other workings. The purpose of the investigations was to determine the water quantity contained in a precisely delimited part of old workings and to compare it with the precisely calculated primary volume of this part of the extracted coal bed.

During the investigations some technical difficulties were encountered along with those associated with interpretation of results. The chief technical difficulty was the measurement of water quantity drained out from old workings through the drain bore-holes. In many cases, some uncontrolled quantities of water inflowing to the old workings were obstacles in the proper realisation of measurement. Operational reasons frequently required stopping the dewatering for a certain time or decreasing the discharge of draining bore-holes. Such disturbances of dewatering old workings rendered the interpretation of measurements more difficult and, sometimes, even impossible. In consequence, in many cases, the results obtained were incomplete or not fully reliable. After a detailed analysis, 12 water reservoirs from the total number of 37 covered by the investigation were selected. Their water capacity was measured with a satisfactory accuracy.

The difficulty of interpretation of the results of measurements encountered in all investigations which reduced the accuracy of obtained results, consisted in the unknown water capacity of roadways situated among inumdated gobs and connected with them. Usually, neither the dimensions of roadways, nor the degree of their caving or self-stowing were known. In general, it was assumed that the water capacity coefficient determined for caved gobs could not be extended for roadways. In particular mines the water capacity of roadways was estimated by assuming that the dimensions mostly encountered in a given mine and the degree of squeezing the roadways depend on the behaviour of roadways in a given coal bed of the mine. Using these estimations and the data read from the mine map, the water capacity of roadways in the dewatered part of the reservoir was calculated and subtracted from the volume of water drained from the workings. It was assumed that the remaining quantity of water derives exclusively from the production workings and that its relation to the primary volume of these workings is the searched water capacity coefficient.

The capacity of galleries usually low with respect to that of whole dewatered reservoir, brought about that the error of determination of the water capacity coefficient, resulting from unexact estimation of roadway capacities, was very small and, in practice, it did not exceed ± 2 %.

In the case of getting coal by caved longwall face system the values of water capacity coefficient show a good correlation with the depth at which old workings were situated. Such a correlation was not found in the case of caved shortwall workings. This may be explained, on one hand, by a small number of dewatered reservoirs /4 reservoirs/ and on the other hand by a moderate depth at which they were situated not exceed 200 m. Thus, the water capacity coefficient of caved shortwall workings was calculated as an arithmetic mean of values obtained from measurements

$$\bar{c} = 0,438$$

The standard deviation of the mean value amounts to ± 0,0128, which is an accuracy for mining purposes.

For caved longwall face workings the results of measurements were used to establish the regression equation of the water capacity coefficient c in relation to the depth H at which the old workings were situated. This equation has the form:

$$c = 0,485\ e^{-0,00205\ H} \qquad /3/$$

where e is the base of natural logarithms.

The graph of equation 3 is shown in fig. 1.

Although the number of experimental data of the water capacity coefficient for caved longwall face workings is small /8 reservoirs dewatered/, nevertheless the relation between the values of coefficient c and the depth of workings is quite distinct. It justifies the use of regression calculus.

The standard deviation of real values of the coefficient c from those estimated with the use of the equation /3/ amounts to ± 0,016, which seems to be an accuracy sufficient for mining practice.

4. Water capacity of sand filled gobs

The water capacity coefficient of sand filling c is equal to the specific yield μ of the sand compressed in workings under the effect of overlying rocks pressure, multiplied by the ratio of the sand layer thickness M to the primary thickness of the extracted coal bed M_o

$$c = \mu \frac{M}{M_o} \qquad /4/$$

Contrarily to the water capacity of caved workings, the water capacity coefficient of workings filled with sand stowing may be tested in laboratory. The tests consist in determination of specific yield of sands having various granular compositions after their compaction in the hydraulic press.

130 samples of sand used for hydraulic filling, taken from various pits situated on the territory of Upper Silesian Coalfield were submitted to tests. In order to establish the relation between the specific yield of sand and the degree of its compression in workings, each sample was placed in the special cylindric container and its specific yield was determined 5 times, namely: in loose state and after compaction of sand in the press. Pressures of 5,2; 10,4; 15,6 and 20,8 MN/m^2, were applied which corresponded to depths of 200, 400, 600 and 800 m respectively, with taking simplificated assumption that after a sufficiently long time the rock pressure in gobs is equal to the product of the depth and the specific weight of overburden, which amounts to 26 kN/m^3, on the average.

Besides the tests on the specific yield, every sample was submitted to size analysis and its characteristic parameters were determinated, i.e. the effective size diameter d_{10} and coefficient of uniformity

$$U = d_{60} : d_{10}$$

The tests allowed to establish for each sand sample the specific yield μ in loose state and after the compaction of the sample in the press at various loads. The measurements of thickness of sand layer in the cylinder before compression M_o and after every compression M, allowed to determine the water capacity coefficient c with the use of the formula /4/.

Consequently, for each sand sample were five values of coefficient c, corresponding to five values of pressure p caused by the press load. In addition for each sample parameters of grain sizes d_{10} and U were determined. This allowed to set up 650 fours of numbers for c, d_{10}, U and p. Next, coefficients of the linear regression of c with respect to d_{10}, U and p were calculated in various combinations of variables and of their logarithms. These calculations aimed at finding such form of regression equation, at which the correlation coefficient could be the highest and the remaining variance the smallest. The equation finally obtained has the form:

$$c = 1,673\ d_{10}^{0,716}\ e^{-0,329\ U}\ e^{-0,0147\ p} \qquad /5/$$

where p is the rock pressure expressed in MN/m^2.

The coefficient of multiple correlation R = 0,682 and the standard deviation s = 0,0572 proves that the correlation is significant on a very high confidence level.

In the case of no data on the quality of sand used to back-filling, it is suggested to take average values of d_{10} and U for an approximate assessement of coefficient c. On the basis of tests on 130 samples of sand taken at random from 9 active and abandoned sand pits, the mean values of size composition parameters are as follows:

$$d_{10} = 0,21\ mm$$

$$U = 2,09$$

with standard deviations from the average ones being of 0,0517 and 0,5011 respectively. The values of coefficient c for sand with such parameters may be estimated by means of the following formula:

$$c = 0,275\ e^{-0,0147\ p} \qquad /6/$$

Its graph is shown in fig. 1.

Adoption of mean values of size composition parameters introduces an aditional error in assessment of the water capacity of old workings. Its mean value m_c may be determined by the formula:

$$m_c = \sqrt{\left(\frac{\partial c}{\partial d_{10}}\right)^2 s_d^2 + \left(\frac{\partial c}{\partial U}\right)^2 s_U^2} \qquad /7/$$

where s_d - standard deviation of d_{10}
s_U - standard deviation of U.

By substituting in the formula /7/ $s_d = 0,0517$ and $s_U = 0,5011$, we get after differentiation:

$$m_c = \pm 0,066 \ e^{-0,0147 \ p} \qquad /8/$$

Consequently, the relative error of the coefficient c resulting from adoption of the mean values d_{10} and U amounts to:

$$\frac{m_c}{c} = \pm 0,24$$

6. Water capacity of gobs supported by packing

The water capacity coefficient of gobs supported by packing may vary within large ranges depending on the quality of material used for packing and the way of its setting. It is convenient to calculate these values, starting from the porosity of bulk density of the material used and from its compressibility. With such a calculation the results obtained will be a little overestimated with respect to the real water capacity of gobs. In order to avoid this error, it would be necessary to adopt the thickness of coal bed M reduced by the average hight of the void left between the packing and the roof of the packed gob. This height can not be established generally. It may be determined in relation to definite gobs if the way of their packing is known.

The compressibility of packing material composed of coarse lumps of carboniferous rocks of the Upper Silesian Coalfield was investigated by Hurysz and Adamek /1/. They established curves of relations between the compressibility and rock pressure for packing with clayey shales /siltstones/, mudstones and sandstones. The curves compressibility of siltstones and mudstones are close to each other on the diagram, while the sandstones show a lower compressibility. Taking into account the prevalence of siltstones and mudstones over the sandstones in the material used for packing in mines and the similar compressibility of siltstones and mudstones the mean values of compressibility of these rocks were calculated and next the resultant curve of compressibility was approximated by the regression equation:

$$S = 0,19 \ p^{0,2} \qquad /9/$$

where: S - compressibility of packing material,
p - overlying rock pressure, MN/m^2.

The water capacity coefficient of gobs supported by packing may be determined by the formula:

$$c = P - S \qquad /10/$$

where: P - the porosity of bulk density of packing material.

The tests on the porosity of bulk density of rocks were carried out on 278 samples of barren rock material used for packing taken from various coal mines. The tests allowed to determine the mean value P = 0,403 with standard deviation of ± 0,12.

Using the equation /9/, an approximate equation determining the relations between the water capacity coefficient of pack-supported gobs c and the overlying rocks pressure p was derived

$$c = 0{,}4 - 0{,}19\ p^{0{,}2} \qquad /11/$$

The graph of equation /11/ is shown in fig. 1.

6. Summing up of results

The water capacity of old workings is the product of primary volume of extracted coal bed and of the number lesser than unity, called water capacity coefficient c.

The values of water capacity coefficient depend on the quality of material filling the old workings and on the degree of its compression by the rock pressure. For caved gobs the empirical relation /3/ was established between the water capacity coefficient and the depth at which the coal bed was worked, on the basis of measurements of quantity of water drained off from dewatered reservoirs. For gobs filled with sand and supported by packing relations /5/, /6/ and /11/ between the water capacity coefficient and rock pressure were determined.

Table 1 shows the approximate values of water capacity coefficient under different conditions. The values of coefficient c for hydraulic filling refer to the stowing sand with an average size composition parameters, i.e. d_{10} = 0,21 mm and U = 2,09.

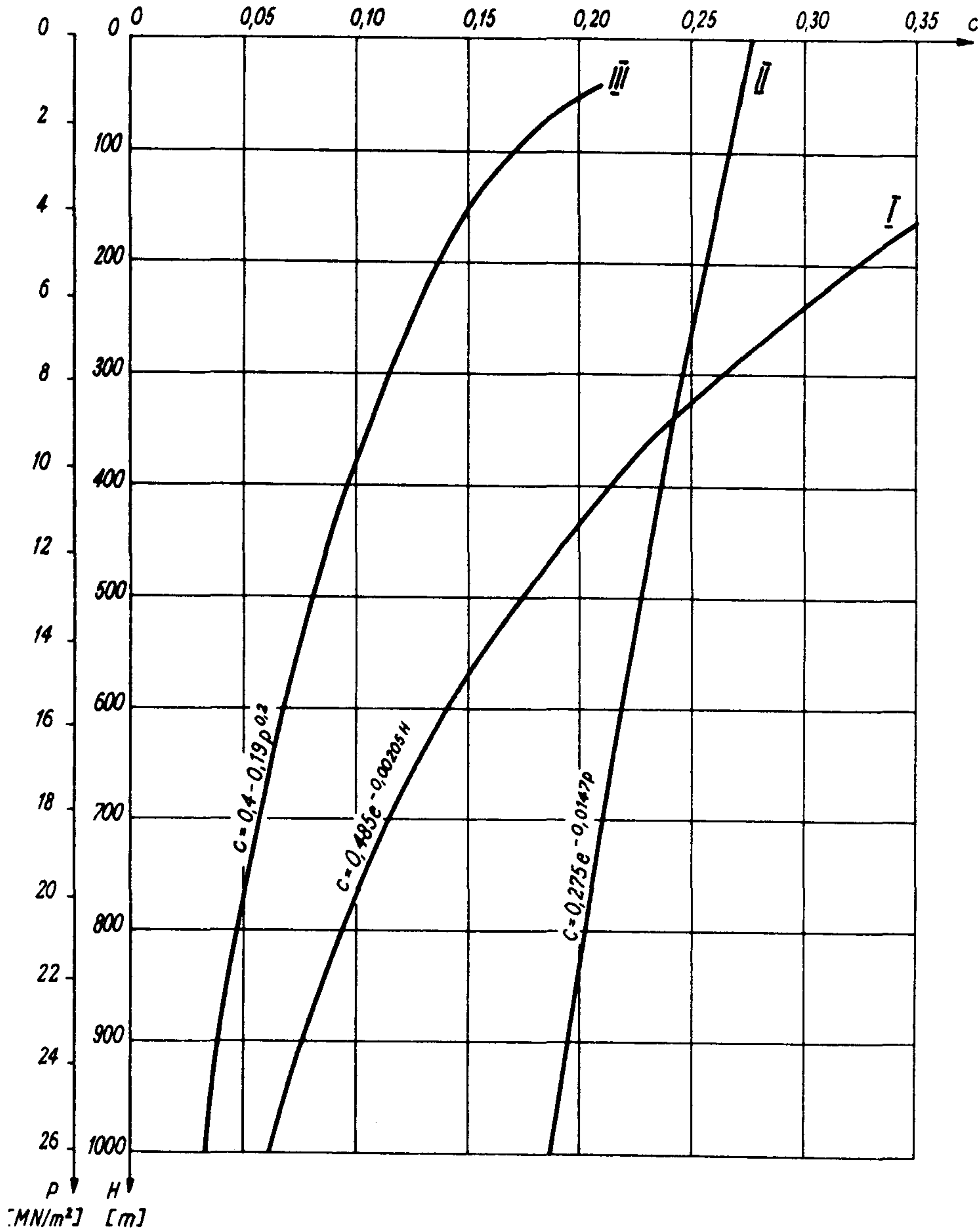

Fig. 1. Water capacity coefficient curves for caved gobs (I), hydraulic-filling (II) and packing (III)

Table 1

Mean values of water capacity coefficient c

Caving			Filling		
Depth of workings m	Shortwall system	Longwall system	Rock pressure MN/m^2	Hydraulic filling	Packing
200	0,438	0,322	5,2	0,255	0,137
400	-	0,213	10,4	0,237	0,097
600	-	0,141	15,6	0,218	0,068
800	-	0,095	20,8	0,200	0,047
1000	-	0,062	26,0	0,187	0,033

The curves of water capacity coefficient values depending on depth or rock pressure, for caving, hydraulic-filling and packing are given in figure 1.

Reference

Hurysz J., Adamek R., 1960. Skruszone skały płonne, jako materiał do podsadzki płynnej. /Crushed barren rocks as a material for hydraulic filling/. Prace GIG, Komunikat nr 265, Katowice.