Water Inrush Prevention in Polish Coal Mines

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ABSTRACT

The short review of hydrogeologic conditions in the three Polish coal basins have been presented as the background for the prevention measures against water inrushes being undertaken in coal mines.

The Polish mine safety regulations concerning water inrush prevention have been discussed, namely:
- classification of sources of the potential water inrushes,
- levels of water inrush risk and conditions of mining operation in the mines facing particular risk levels,
- determination of the dimensions of protecting pillars to prevent water inrush to mines,
- protection of surface water reservoirs and their earth embankments in regions submitted to mining deformations.

Three examples of coal mining being carried out under water bodies have been presented.

HYDROGEOLOGICAL MINING CONDITIONS IN POLISH COAL BASINS

Hard coal in Poland is mined in the three Carboniferous coal basins: Upper Silesian, Lower Silesian and Lublin.

The Upper Silesian Coal Basin

In the north-eastern part of the basin and in the area of the main anticline the Carboniferous strata are overlain by the Quaternary deposits varying in thickness from several metres in water divide areas to several dozen metres in river valleys. Water inflow into the mines is primarily the result of infiltration of surface water. The sandy nature of the Quaternary deposits creates the danger of both inrushes of water with loose material into the mine workings and, simultaneously. surface deformation caused by drainage of the water-bearing strata. This type of danger is dominant in the eastern region of coal basin, where highly erodible Carboniferous sandstones underlie the Quaternary deposits.

Triassic formations overlay the Carboniferous in the northern and north-western region of the coalfield. These are argillo-arenaceous deposits of Bunty Sandstone with a thickness of approximately 30 m and a limestone-dolomitic series of the Shell Limestone deposits as much as 200 m thick. When mining is carried out close to the Carboniferous roof, there is a danger of an inrush of water with sandy material from the strata of Bunty Sandstone, as well as water inrush from the fissured karst acquifer of the Shell Limestone.

The Carboniferous deposits in the central, southern and south-western parts of the basin contain a thick body of Tertiary clay, totalling several hundred metres, that isolates the Carboniferous strata from infiltration of surface water. The sandy-gravelly deposits in the Tertiary footwall that overlay the Carboniferous formation in the southern part of the basin contain gas and water under pressure as high as 6 MPa, which presents a great danger for mining operations near the Carboniferous roof.

The Lower Silesian Coal Basin

In the western part of the basin, the Carboniferous strata are covered by Quaternary deposits that are no more than 10 metres thick. Years of mining have resulted in virtually complete draining of the Carboniferous strata, and the intensity of inflow into mine workings is closely related with the quantity of precipitation.

In the eastern part of the basin the Westphalien formations are covered by a thick blanket of deposits of the Stephanian stage and of the Permian and Quaternary periods. Owing to the retarded infiltration of atmospheric water into productive Carboniferous strata, inflow into mine workings is stabilized, and there is a slight correlation between inflow intensity and precipitation.

The Lublin Coal Basin

The overburden of Carboniferous strata contains deposits from the Jurassic, Cretaceous and Quaternary periods, which has given rise to two water-bearing complexes. The upper one is made up of loose Quaternary deposits and fissured, karstic Upper Cretaceous deposits with total thickness of 150 to 200 m. The lower one, with a thickness of approximately 130 metres, is composed of Albian deposits of sands and loosely bound sandstones and also limestones and dolomites from the Jurassic period, which in the floor change in places to aleurolites, argillites and friable sandstones.

At present, the main danger of water inrush to mines stems from the accumulation of large volumes of water under pressure of approximately 7 MPa in formations of the Jurassic period. Moreover, there is a complex of weak rock on the boundary of the Carboniferous formation which can soften under filtration pressure creating the danger of an inrush of water with loose material into mine workings near Carboniferous roof.

WATER INRUSH PREVENTION IN POLISH MINE SAFETY REGULATIONS

Classification of risks of water inrush

Inrush risks sources are grouped into two categories depending on the freedom of water movement in the rock and the associated inrush impact:

1) body of water that has unlimited freedom of movement,
2) body of water that has limited freedom of movement.

The first category embraces bodies of water on the surface, and flooded mine workings. Hydraulic resistance in such water bodies is minimal and the water is therefore free to migrate.

The second risk category covers water-bearing strata and fractures, and also non-filled or improperly filled abandoned boreholes which may be in contact with some bodies of water. In this cases water movement depends upon the permeability of the rock in which the water is located.

Risk levels for water inrush have been introduced in order to counteract such hazard and to ensure mine safety. Assessment of a mine or part thereof and its classification in a particular level of inrush risk is based upon the location of current or planned mining operations in relation to the risk sources, and the type of strata separating the risk sources from the operations. The risk of water inrush can be classified into three levels:

Coal mines or parts thereof face a level I risk if:

- bodies of water on the surface and water-bearing horizons are isolated from mine workings by impermeable rock,
- hydrostatic water resources are drained away, and water flowing into workings stems from hydrodynamic resources.

In regions with a level I risk of water inrush, the mine operations are conducted in accordance with the general mining safety regulations, and no additional regulations need to be applied with regard to inrush risk.

The level II risk applies to a mine or part thereof if:

- the bodies of water on the surface and flooded gobs can lead by means of infiltration to inundation of workings,
- a stratified aquifer at the top or bottom of the deposit is not isolated by a sufficiently thick and solid stratum,
- there is an aquifer in the fractured or/and cavernous rocks that is isolated from mining operations,
- there are water-bearing faults that have been surveyed

for rate of water yield and localization,

- there are boreholes which might lead to direct contact between mine workings and surface or underground water bodies, which have not been properly filled or for which no data are available on how they were filled.

In regions of level II risk, mining can be undertaken only in the parts surveyed by means of gate roads or exploring headings. If the advancing technique is employed, the gate roads or exploring headings must be at least 50 m ahead of the face. When workings reach the zones of inrush risk, exploring bore-holes must be drilled for at least 25 metres. The mine manager specifies the working sites for which emergency exit routes must be established, and attends to the installation of an alarm system.

The level III risk applies to a mine or part thereof if:

- bodies of water on the surface offer the possibility of direct water inrush into the mine workings,
- a water-bearing horizon of the fractured or/and cavernous rocks occurs directly on the top or bottom of the deposit,
- flooded gobs are located directly in the deposit or in the roof or bottom of the workings,
- there are water-bearing faults with inadequately investigated water content and localization,
- there is the possibility of an inrush of water with loose material into the workings.

In areas exposed to level III risks exploitation can be carried out only in those parts that have been explored with the help of gate roads or exploring headings which must be no less than 50 m ahead. The mine manager establishes the mining procedure to be employed (advance gates, extend of advance, minimum distance between workings, etc.). When driving a working through a zone of tectonic failure in which a large inrush of water with loose material might occur, work safety procedures must be devised case by case.

Protective pillars to prevent water inrush

A protective pillar is a rock mass left between a risk source and an active working to prevent an inrush of water or water with sand in the mine or interfere with normal mining operations. It is called for in hard and erosion resistant rocks when the risk cannot be eliminated.

Protective pillars can be grouped into three categories depending upon the location of the risk source in relation to the active working:

- pillars perpendicular to the bedding (vertical pillars),
- pillars parallel to the bedding (horizontal pillars),
- pillars around non-filled boreholes.

The formulae below enable minimum values to be determined for the dimensions of protective pillars. The following symbols are used in the formulae:

D - dimension of the protective pillar in metres,
G - thickness of the seam being worked or lateral dimension of the gate road in metres,
M - reduced thickness of the seam in metres,
α - angle of dip of the seam,
p - water pressure in the sump in megapascals,
a - correction factor for the borehole distortion in metres.

The reduced thickness of the seam can be calculated using the following formula:

$$M = G * \eta$$

where η - filling compressibility factor, for which the following values are assumed:

η = 1.0 for extraction with caving,
η = 0.5 for extraction with dry filling,
η = 0.2 for extraction with hydraulic stowing.

For working a thick seam with roof caving, the reduced thickness can be calculated using the following formula:

$$M = \sum_{i=1}^{n} \frac{Gi}{i}$$

where: i - stratum number
Gi - exploited thickness of the ith stratum
n - number of strata.

The formulae for calculating the critical dimension of the protective pillar appear in the following table:

Type of pillar	Category I	Category II
Perpendicular to the bedding (vertical)	$D = 40 * M$ $D >= 40$ metres (1)	$D = 15 * M$ $D >= 15$ metres (2)
Parallel to the bedding (horizontal)	$D = G\sqrt{60p+0.15G \sin\alpha} \pm 0.4G \sin\alpha$ $D >= 20$ metres (3)	$D = 20$ metres (4)
Around non-filled boreholes		$D = 20 + a$ (5)

In formula (3), the sign + is used when the water body is located higher than the active workings (in the direction of seam pitch), the sign - is used when it is lower.

Protective pillars which are perpendicular to the bedding or vertical and are located beneath risk sources classified in first category, must be designed in keeping with the following requirement. Shale must make up not less than 50 per cent of the column of strata forming the protective pillar, and the rock mass forming the pillar must be intact and contain no faults or fractures which might open as a result of mining. If these conditions cannot be met, mining must be carried on under special requirements appropriate to the local mining and geological conditions.

When the seam dip angle α is less than 15°, or when the active workings are located near the water body (in the direction of the strike of the seam), formula (3) is as follows:

$$D = G\sqrt{60 * p} \qquad D >= 20 \text{ metres.}$$

When using formula (5), the value of correction factor 'a' should be based on the results of distortion measurements taken once boring has been completed. If such measurements are not available, the value 'a' should be a function of depth H, in accordance with the following table:

H [m]	200	400	600	800	1000
a [m]	0	0	4	10	17

Those boreholes for which it is uncertain whether filling was undertaken properly must be regarded as non-filled.

PROTECTION OF SURFACE WATER RESERVOIRS EMBANKMENT

Embankment of water reservoirs are very susceptible to surface deformations brought about by underground mining. The ever-resent risk of collapse combined with the impact of mining may endanger the structure and lead to an accident.

Water reservoirs in mining regions can be grouped into four categories of importance, taking into consideration:
- danger that might arise from damage of the embankment,
- location of the reservoir with regard to mine workings,
- height of the water level.

Records of collapse at mining sites prove that the main impact on the strength of embankments is the positive horizontal deformation E of the subsoil as a result of mining. The following limits for horizontal deformation E in embankments have been established:

$-9 < E <= +3‰$. for embankments made of loose soils or burnt material from spoil heaps,

$-9 < E <= +6‰$. for embankments made of cohesive soils or non-burnt and easily eroded argillites from spoil heaps.

With regard to the negative impact of rock deformations on stability, it is assumed that embankments of the reservoirs located in mining areas must have a higher coefficient of stability than in other areas. The following table indicates the required stability coefficient for each category of water reservoir and type of load.

Type of load	Category of reservoir 1	2	3	4
Normal	1.50	1.35	1.25	1.15
Special	1.35	1.25	1.15	1.10

For earth-quakes generated by mining with intensity of 7 to 8 on the Mercalli-Cancani-Sieberg scale, the embankments must be no higher than 20 m, and 15 m for an intensity of 9 .

EXAMPLES OF COAL-MINING UNDER WATER-BEARING STRATA AND FLOODED GOBS

Working seam 308 in the 'Lenin' mine

The 'Lenin' mine is located in the northern flank of the main syncline in the Upper Silesian Coal Basin. In the working area of seam 308, Carboniferous strata form a local depression with side inclination from 6 to 20° . A network of faults with throws varying between several dozen centimetres and several metres traverse the strata.

Seam 308, with a thickness ranging from 2.8 m to 4.5 m, occurs at a depth ranging from 280 to 410 m in the top part of the Orzeskie strata (Westphalian B), which take the form of shaly deposits interbedded with two sandstone bands. The total thickness of the Orzeskie strata overlying the seam varies between 50 and 70 m. Laziskie strata (Westphalien C) occur higher up and are composed of a suite of coarse-grained sandstones, conglomerates in places, with a thickness ranging from 100 to 240 m.

The Laziskie sandstones form a high water yielding aquifer. The water is under pressure, and its table stabilized in 1984 at depth of between 31 and 47 m. In Orzeskie strata above seam 308 lie two inundated sandstone bands which are fed by water from overlying strata, primarily in zones of tectonic dislocation.

The seam has been worked since 1977, by the transverse long-wall technique with caving. No increased water inflow occured during exploratory work or when traversing fault zones. Once working of the seam commenced, increased water inflow was observed from the roof in the area of the face line in the long-wall and in the collapse zone. The first increase of water inflow occured in every new wall when the panel being worked by the long-wall technique was between 50 and 100 m long. These inflows, in pulses and with an output varying between several hundred cubic decimetres and 14 cubic metres per minute, often contained important quantities of mud produced by the washout of shales from the roof. Repeated water inrush with roof collapse led to serious accidents and interfered with mining operations.

An analysis of the reasons for and the mechanics of concentrated water inrushes showed that they were caused by the enormous tectonic pressure of the rock mass, distinct sedimentary anomalies, the poor binding quality of the roof rock and unfavourable hydrogeological conditions due to the water-bearing sandstones of the Laziskie strata.

In order to ensure maximum safety seam 308 was worked in compliance with the safety regulations for level III water inrush risks. In gate roads that traverse zones of tectonic failure, in deep eroded sections in the roof of the seam and in areas where roof has collapsed, a reinforced arch support has been used with complete roof lagging.

<u>Working seam 304/2 in the 'Komuna Paryska' mine</u>

In the 'Komuna Paryska' mine, located in the eastern part of the Upper Silesian Coal Basin, seam 304/2 has been worked at depth ranging from 80 to 176 m under the river.

Seam 304/2, with a thickness varying from 2.8 to 4.4 m, is between 15 and 176 m deep with a slope angle of 3 to 8^{o} in a southern direction. The Carboniferous roof is made up of sandy Quaternary deposits with a thickness of several metres. The Carboniferous formation occurs in Orzeskie strata (Westphalian B). A series of shales between 16 and 20 m thick occurs directly above the seam, and a series of sandstones with a thickness of approximately 65 m is located in the Carboniferous roof.

Hydrogeological exploration has shown that neither the Quaternary deposits nor the Carboniferous sandstones were inundated, because they were drained as a result of the working of seams outside the pillar left under the river. The river with a water discharge rate of 37 m^3/s, was the main source of water inrush risk.

Work on seam 304/2 began at a depth of 170 m, in an area bounded by workings in which no tectonic dislocations had been found. The seam was worked by the long-wall technique with hydraulic stowing, using two long-walls with an average face length of 200 m, a height of up to 2.8 m and a maximum face advance of 30 m. Level II water inrush risk was applied for working at a depth of between 170 and 130 m below the river bed, and level III for work at depths of less than 130 m.

During the first stage of extraction conducted at 170 to 100 m below the river bed, maximum roof exposure did not exceed 6.9 m, and the filling intervals were 3.0 m. Mining was conducted without explosives. During extraction, hydrogeological observations were conducted in the workings and measurements carried out along observation lines on the surface.

There was a constant water inflow to the workings of 0.3 to 0.5 m^3/min, that occurred primarly in the gate roads. A chemical analysis of the underground water showed no hydraulic communication with water from the river.

Shaft measurements showed a maximum settling of W = 222 mm and horizontal deformation E between -1.8 and +1.3 per mille. The physical and mechanical properties of the rocks underlying seam 304/2 were tested, and geophysical tests were also conducted for the purpose of determining the effect of mining on the block and its level of foliation.

The second state of extraction involved the part of the seam 100 to 80 m below the river bed. Stowing intervals were reduced to 2.5 m and the height of the wall did not exceed 2.8 m. No wall could outstrip the other by more than 25 m and the coal layer left in the roof was no less than 0.5 m thick.

Working seam 341 in the 'Murcki' mine

In the 'Murcki' mine, located in the northern part of the main syncline in the Upper Silesian Coal Basin, seam 341 has been worked below the inundated caved gobs in seam 334.

Both seams are found in a group of Orzeskie strata (Westphalien B) which take the form of a series of shales with numerous coal seams interbedded with sandstones. In the upper part of the section above seam 341, sandstones form an interbed 10 to 20 m thick. The Carboniferous strata have a slope of approximately 2° in a south western direction.

Seam 334, 1.4 to 1.5 m in thickness, was worked by the longwall method, advancing the face to the strike, with caving of the roof, in 1975-1977, at a depth ranging from 250 to 280 m. After mining had ended and draining had stopped, in the abandoned workings located lower down, a sump formed with a water level of +65 m and a capacity of 236000 m^3.

Seam 341, which is from 1.8 to 2.3 m thick, occurs at a depth of 330 to 360 m, approximately 85 m below the level of the inundated gobs in seam 334. The seam 341 has been worked by the long-wall method with caving in accordance with the safety regulations applying to level II water inrush risk. The gobs resulting in the seam 341 has remiained dry, and no water outflow has been observed.

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