Delimiting of Safety Pillars to Separate Multi-layer Thick-seam Mining Systems from an Aquifer in an Adjacent Flooded Mine

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Abstract
In southern Poland, mine closures have led to the flooding of mine voids and turned them into large volume water aquifers with high pressures, creating a high risk of water inrush into the adjacent active mines; the results could be catastrophic. Safety pillars are generally established between the mines to prevent a sudden water inrush. However, the methodology of their delimiting has been made problematic at a hard rock mine in southern Poland due to increased water depth in the abandoned mine and the decision to mine additional levels. Procedures are suggested to delimit pillar dimensions in this real world example.

Key words: safety, hydrogeology, water conditions, safety pillar

Introduction
In the AB mining field in the Upper Silesian Coal Basin (in southern Poland), a coal mine operates in seam 510 (the thickest seam of the entire Basin) near a water aquifer that formed in an adjacent mine when it partially flooded. The aquifer exerts about 3.0 MPa of pressure on the bedrock in the area now being actively mined in seam 510. To prevent water inflow from the flooded aquifer into the working mine, a safety pillar has been established between them. The pillar's dimensions were calculated based on the assumption that seam 510 would be mined using a standard one-layer system at a thickness of 3.0 m. However, current plans to mine the next two layers of seam 510 change the risk of water inflow.

Geological & mining conditions
Boreholes have been drilled in layer II of seam 510 at a depth of about 800 m, under the goaf of layer III. Examinations of the goaf through such boreholes found no water aquifers; the outflows from the boreholes were a few L/min (Kubica 2007).

During preparation work in layer II, water was reported dripping from the ceiling. On 15th March 2007, a large water flow (0.20 m^3/min) developed. The outflow rate increased systematically and on 22nd March 2007, it reached 0.80 m^3/min. Such a high outflow at such a significant depth is a rare phenomenon and has caused difficulties in the continued working of the mine. This high outflow was probably caused by drainage from so-called Weber's Cavern, which was formed during exploitation of longwall 01b in 2002.

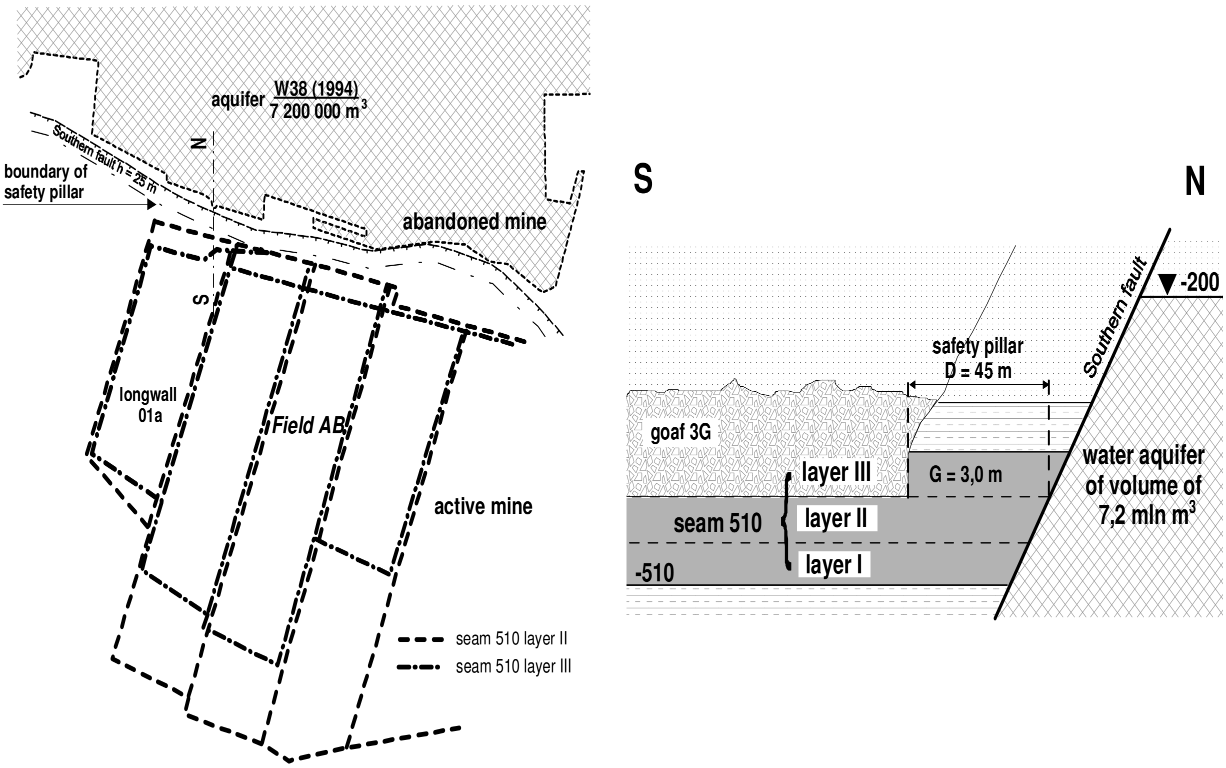
In the AB field, the mine exploited layer III of seam 510 from 2002-2006. The mining system was longwall with roof collapse extending for a height of 3.0 m. Plans are underway to exploit layer II under the goaf of layer III; four longwall panels are planned, again with roof collapse extending for 3.0 m. Another layer of this seam may be mined in the future.

Field AB is a geological block bound by high magnitude faults. The highest risk of water inflows for the planned mining exists in the northern part of the deposit, which is close to the abandoned mine, across the Southern Fault, which represents a significant mine water aquifer (fig. 1).

Hydrodynamic situation of the AB mining field
Stationary pumping systems operated in the abandoned mine until the end of 2000. When pumping was stopped, and flooding began of the workings under the level of –197.5 m, a mine water aquifer of about 7,200,000 m^3 was formed. Since 2001, the abandoned mine has been pumped with two deep well aggregates, with pumping rates of 7.2 m^3/min each, installed in the "Bartosz II shaft." The reason for pumping is to keep the water level in the voids at a level of -204.5 to -197.5 m (this is a retention aquifer). This is necessary to protect the active mine from the water hazard.

The aquifer and the active mine are bounded by the Southern Fault. According to a previous investigation (Tajduś 1999), the fault plane is filled with clay and sandy material and is not waterbearing. However, the possibility of leakage through the fault into the field AB can't be ignored, although so far it hasn't been noted. Based on water analyses, the sodium/chloride indicator (rNa^+/rCl^-) in the water flowing into the workings in seam 510 amounts to 0.78 - 0.80.

Figure 1 *Map of seam 510 (left) and a geological cross-section in the area of the aquifer (right).*



This is proof of the relict and metamorphic origin of the water, so obviously the water exchange in the bedrock is very limited. To monitor possible water leakage from the aquifer into the bedrock across the fault, it is recommended that a borehole be drilled from the workings in the northern part of the field into the bedrock. Water from the bedrock above seam 510 is currently highly mineralized (130 – 143 g/L), whereas the water in the aquifer across the fault has lower mineralization (about 15 g/L). If any leakage from the aquifer across the fault should occur, this should result in lowering the mineralization of the water and - at the same time – increasing the sulphate concentrations (Kubica 2007).

To prevent a sudden water inrush into the mine workings in seam 510, a safety pillar was established in the northern part of the AB field (fig. 1). The dimensions of the pillar (Tajduś 1997) were determined based on the equation for the pillar parallel to the lamination, taking into account the exploitation (with roof collapse for a height of 3 m) and the water level in the abandoned mine at -350 m. This resulted in an estimated pressure of about 1.5 MPa posed to the planned workings. The width of the pillar was calculated to be 28.5 m. As the mine area is also potentially exposed to tremors, a safety factor was added, resulting in a final width of 35 m. However, when the mine water level in the flooded mine increased to about -200 m, the water pressure increased from 1.5 to 3.0 MPa. As a result, the size of the safety pillar had to be increased, to at least 40.3 m. It was finally determined best to make it 45 m. There have been no significant water outflows in the active workings of seam 510, only dripping. Therefore, the pillar was safe enough.

However, the previous analyses (Tajduś 1997, Water Hazard Commission) assessed the water hazard assuming the exploitation of seam 510 in one layer, 3.0 m thick. Now, the projected exploitation in two other layers of seam 510 changes the water hazard in the area, causing us to reassess the situation.

Assessment of water hazard for planned mine works from the aquifer in the adjacent abandoned mine

Taking into account current hydrodynamic, geologic, and mining conditions, the aquifer formed in the voids of the adjacent abandoned mine is the main source of water hazard for planned exploitation in layer II of seam 510 in the AB mine field.

The pressure exerted by the aquifer with a volume of about 7.2 million m^3 on the bedrock in the area of planned mining was estimated to be about 3.0 MPa. Inflow of a portion of the water at a rate exceeding the capacity of mine pumping systems would cause the active mine to be flooded up to the water level of the abandoned mine. That is why a safety pillar of 45 m was instituted to protect the active mine from a water inrush before starting exploitation in layer III of seam 510.

Currently, the mine plans to exploit the layer II of seam 510 at a level of -570 to -510 m beneath the exploited layer III. Assuming that the width of the safety pillar could be determined just as it was earlier, as a pillar parallel to the lamination and assuming that the source of water hazard has infinite water movement possibility, the width of the pillar would be (Konstantynowicz et al., 1974):

$$D = G\sqrt{60p + 0{,}15G^2 \sin^2 \alpha} + 0{,}4G^2 \sin \alpha$$

For seams that dip <15°, the simplified formula can be used:

$$D = G\sqrt{60p} = 80 \text{ m}$$

where:

D – critical dimension of the pillar, [m],

G – height of the longwall, [m],

p – pressure of water in the source of the hazard in the area of forecasted exploitation [MPa],

α – dip of the seam, [degrees],

Intact bedrock (the safety pillar) ensures the efficient protection of the active mine from water inrush. Exploitation of layer III of the coal seam is in this context the least pillar dimensions. Each following mine exploitation must be done taking into account the weakly reconsolidated goaf in the roof. Delimiting of the pillar width in layer I and II depends on treating the edge of exploitation in the exploited layer III.

1. If the edge of exploitation and the voids range are treated independently and as a source of water hazard, both vertical and lateral safety pillars should be determined. If so, further exploitation under the goaf of layer III would be impossible.
2. If the edge of the goaf of layer III from the side of the aquifer were to be treated as a boundary of a hazard source, then a 40 m lateral pillar would be required, which means that the pillar on the side of the fault would have a total width of 80 m. The exploitation should be moved another 40 m away.
3. The existing boundary pillar should be treated as the main element protecting field AB from the water hazard. Also, the forecasted range of influence would be affected by the exploitation with roof collapse in layers II and I; their overlap with the impact of exploitation done in layer III should be taken into account. Assuming that the angle of goaf stability would be $\Phi=45^{\circ}$ and the height of the goaf would be h = 3G, the edge of layer II should be moved from the edge of the goaf towards the center of the mine field for it will also affect the safety factor for moving the area of impact from planned exploitation in layer II towards the center of main impacts, so that the total impact, measured as the shift of the post-mining depression edge, is not increased.

Summary

An intact bedrock safety pillar offers the only efficient protection from water inrush into an active mine. In the case of coal seams exploited in a multi-layer system, the delimitation of its width using standard equations is problematic, mainly due to the fact that earlier mining has affected the bedrock. In such cases, site-specific geomechanical and hydrogeological analysis is necessary. However, this solution needs further investigation and may need to be adjusted to mesh with the Polish mining regulations and the rules of safe mining.

Acknowledgements
This work is part of a scientific project, 2006 – 2009, funded by the Polish Ministry of Science and Higher Education.

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