Water Inrush Protection Criteria and Dewatering Scheme at Sakog Brown Coal Mine, Trimmelkam, Austria

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ABSTRACT

The authors describe the basic features of the SAKOG brown coal mine geology, hydrogeology and geotechnics. They present and discuss the safety criteria against water inrushes that are applied in this mine as well as the procedures used in order to predict the necessary steps in the preliminary dewatering of the hanging wall and bottom wall aquifers.

INTRODUCTION

The brown coal mine of the Salzach-Kohlebergbau-Geselschaft m.b.H. (abbreviation "SAKOG") lies about 30 km north-northwestward of the town of Salzburg, Austria. The shaft is situated in Trimmelkam, some kilometers to the east of the Salzach river which here separates Austria and Federal Republic of Germany.

GEOLOGY AND STRUCTURE

On the helvetian basement constituted of moraine gravels, sands and clays were deposited up to three well defined coal seams, after the helvetian sea turned to sweet-water during the badenian era (tortonian). These seams are separated by sandy to clayey strata, building the bottom and the top of the seams as well. All these strata form generally a 35 m thick package, with a fourth, in this area unproductive, coal seam on the top. The badenian strata are overlain by sarmatian sandy to gravely and clayey sediments. All this is covered by pleistocene (quaternary) fluvioglacial deposits and moraines of the Wurm age, which have to be accounted for the picturesque landscape of the area. Quaternary deposits are mostly 30 m thick and are becoming thicker southwards, where they cut previously eroded coal seams. These were cut off by the glacial erosion to the west as well. To the east, the coal seams are becoming thinner and unproductive, while to the NNW the coal seams disintegrate in a series of thin coal measures, which are technically not exploitable. The total exploitable area is therefore rather restricted and today mostly exhausted. By now, only two areas Tarsdorf-Ost and Weilhart, are left for further exploitation, with only the bottom coal seam productive.

HYDROGEOLOGY

The following aquifers can be identified to exist in the studied areas and regionally within the quaternary, sarmatian and badenian deposits from the top downwards: 1. quaternary gravely to sandy aquifer, 2. upper sarmatian gravely to sandy aquifer, 3. lower sarmatian gravely to sandy aquifer, 4. badenian aquifer of 3. Schotter, 5. badenian aquifer of 2. Schotter, 6. badenian aquifer of 1. Schotter.

It was found that the badenian aquifers are hydraulically interconnected, but do not communicate with the sarmatian or quaternary aquifers within the limits of SAKOG mine era. Though they may hydraulically communicate with the overlaying aquifers somewhere on their northwestern or northern borders, this could not be detected. Hydraulically, they behave as partly unlimited confined aquifers, which was proved as well by the short-term pumping tests as by the long-term history of the water inflow from the 2. Schotter after the water inrush that occurred in Tarsdorf-Ost area in january 1985. For the aquifers of 1. badenian Schotter and of 2. badenian Schotter the following hydraulic parameters were defined for Weilhart and Tarsdorf-Ost areas:

Parameter	1.Schotter aquifer	2.Schotter aquifer	
	Weilhart	Weilhart	Tarsdorf-Ost
Permeability	$4.75*10^{-6}$ m/s	$5.79*10^{-5}$ m/s	$3.47*10^{-5}$ m/s
Transmisivity	$4.00*10^{-5}$ m^2/s	$3.74*10^{-4}$ m^2/s	$3.00*10^{-4}$ m^2/s
Storativity	$1.97*10^{-4}$	$4.17*10^{-5}$	$7.82*10^{-5}$
Specific storativity	$3.01*10^{-5}$ m^{-1}	$6.51*10^{-6}$ m^{-1}	$9.05*10^{-6}$ m^{-1}

The groundwater level in these aquifers prior to the water inrush in january 1985 was reconstructed to have been at 440 m above sea level (coal seam lies between 290 and 340 m above sea level). Now it is affected by the inflow to the mine after the already mentioned water inrush.

SOIL MECHANICS

A series of laboratory tests and pressiometer in-situ measurements was performed in order to define the bottom wall and top wall strata soilmechanical characteristics. It was found that 1. Zwischenmittel and 2. Zwischenmittel do not differ detectable one from another, but they do differ within themselves, since they are not homogenous. In the following table only the data relevant for the criteria are presented, due to the lack of space (symbols are: U for silt, T for clay, fs for fine sand and K for coal):

Parameter	Mean value	Standard deviation
Specific weight (U,T)	27.5 kN/m	0.23 kN/m
Natural volumetric weight (U,T)	21.4 kN/m	1.04 kN/m
Natural volumetric weight (K)	13.3 kN/m	0.56 kN/m
Splinter volumetric weight (U,T)	10.5 kN/m	0.28 kN/m

SAFETY CRITERIA AGAINST WATER INRUSHES

When defining safety criteria against water inrushes we had to take into account the following: 1- safety criteria for hanging and bottom walls have to be defined separately; 2- the bottom and hanging wall protective strata belong to the rocks subject to piping process; therefore no through-flow can be admitted without risk of erosion; 3- scatter of the registered elastic rock properties of the protective layers is such that no mathematical modeling could be safely applied; 4- under natural stress conditions hanging and bottom wall strata are in the plastic state, except for the coal measures; 5- no in-situ measurements of caving in process were possible in the mine.

Safety criteria against hanging wall inrushes

We therefore applied the results of our experiences in Velenje mine, Yugoslavia, where an extensive experimental research work was realized recently. When the long wall face is advancing, an area within which the direct caving-in process occurs can be defined as a function of the height of the excavation. We found out (3) that in Velenje mine the directly caved-in area has 2,5-times the height of excavation, and the strata over this area are plastically deformed in case that the initial vertical stress allows for plastic deformation. It was found out (5) that the height of caving-in process can be derived by the following simple formulas:

$$h_o = (x+\Gamma)\ .V = \frac{\gamma_p}{\gamma_p + \gamma_r}\ .V \qquad (1)$$

where are h_o - height of the caving-in area, measured from the bottom of the excavation (m), V - height of excavation (m), x - factor denoting the ratio of the caved-in height over the excavated area to the height of excavated area, γ_p - natural volumetric weight (kN/m), γ_r - splinter volumetric weight (kN/m)

When in the thick seams several successive cuts are performed (not the case in SAKOG mine) then the volumetric weights are dependent on the number of cuts performed:

$$\gamma_p = \gamma_{p_o} . N^a \quad \text{and} \quad \gamma_r = \gamma_{r_o} . N^b \qquad (2)$$

where are γ_{p0}, γ_{r0} - respective initial weights, N - number of cuts, a,b - experimentally defined exponents.

For SAKOG mine N=1, and data from laboratory tests could have been directly applied.

From the data on mechanical properties of the strata it follows that =21,4 kN/m with =1,04 kN/m and =10,5 kN/m with =0,28 kN/m. Taking into account 99,7 % confidence level and the worst possible case =18,28 kN/m and =9,66 kN/m. From this, the factor x is as follows:

$$x = \frac{\gamma_p}{\gamma_p - \gamma_r} - 1 = \frac{18,28}{18,28 - 9,66} - 1 = 1,12 < 1,2 \qquad (3)$$

After the height of the caving-in process was defined, knowing that the height of excavation in SAKOG mine is 2,2 m, the admissible water pressure in hanging wall aquifer was defined as a function of the thickness of the unbroken hanging wall protective layer. For the simplicity and the lack of experimental data we have not applied here the elaborated Velenje formula (4), but adopted the approach of critical hydraulic gradient as accepted in similar condition in the coal basin of Jyhomoravska panva in Czehoslovakia (2). Here, the maximum allowable hydraulic gradient for the undisturbed hanging wall strata is i_c = 0,05 MPa/m. Therefore, the equation of maximum permissible water pressure as a function of hanging wall thickness M_h and the height of excavation V for the SAKOG mine is as follows:

$$p_h \text{ (MPa)} = (M_h - 1,2 * V) * 0,05 \text{ MPa/m} \qquad (4)$$

Safety criteria against bottom wall inrushes

According to (2) the allowable hydraulic gradient towards bottom wall aquifer is 0,07 MPa/m. We applied this to the unbroken part of the bottom wall. In our experiences in Velenje mine, we could evidence no rock fracturing process occurring during the excavation process in the bottom wall. This does not mean, however, that we have measured no stress fluctuations and no deformations, but that the eventual breaking process eventually occurs only behind the supports, where the bottom is depressurized. Yet, the bottom is very quickly reloaded by the caving-in material. The size of unloaded area can be compared to that of the advance gate , where we defined the depth of affected area seismically to be about 0,5 m. We have added this value to the criterion cited under (2) as an additional safety measure and the formula for the definition of the maximum permissible bottom wall aquifer pressure in SAKOG mine is as follows:

$$p_b \text{ (MPa)} = (M_b - 0,5) \times 0,07 \text{ MPa/m} \qquad (5)$$

where M_b denotes thickness of bottom wall protective layer.

Results of the application of the safety criteria

Calculation and mathematical modeling of the hanging and bottom wall aquifers have shown that for the Tarsdorf-Ost area a sufficient hanging wall aquifer depressurization can be achieved by means of surface dewatering through pumped wells. For the Weilhart area, on the contrary, the hanging wall aquifer must be dewatered, while the bottom wall aquifer must only be depressurized. Unfortunately, both objectives can be achieved only by a combination of surface dewatering through pumped wells and of in-mine dewatering by the dewatering boreholes drilled from the advance gates and main ways. Permissible water pressures in the hanging wall aquifer and the residual water pressures after some selected period of dewatering through wells and prior to the in-mine dewatering were calculated by the mathematical model SUTRA (6), adapted by Mr. Supovec to allow for the topography of the aquifer and for the depressurization effects that occur in the aquifer during the dewatering process.

IN-MINE DEWATERING SCHEME CALCULATIONS

It is important to know, whether the hanging wall aquifer, that has to be additionally dewatered from the mine needs a long additional preliminary dewatering. Flow to the caving-in area of the aquifer over the long wall can be assimilated to a dewatering gallery. In an unconfined aquifer is the flow to the gallery, according to (1):

$$Q = 2 \times 0{,}33 \times L \times H_0 \times \sqrt{(H_0 \times k \times n_e / t)} \qquad (6)$$

where are L - length of the long wall, H_0 - height of the water in the aquifer, k - permeability of the aquifer, n_e - effective porosity, t - time from start of the inflow.

When the preliminary dewatering is applied by means of dewatering boreholes from the advance gates, the mean water level between two gates, as a function of their distance and the time of the preliminary dewatering, can be defined as follows:

$$H(L,t) = 0{,}47 \times H_0 / \left[1+1{,}12\times((t \times k \times H_0)/(n_e \times L^2))\right] \qquad (7)$$

where the symbols are as previously defined.

For the SAKOG mine case, the calculations showed that without additional preliminary dewatering in the mine the saturated thickness of the aquifer that persists after the dewatering to the surface (H_0 =5,5 m) yields at a 120 m long long wall face initial inflow (t=60 sec) about 317 l/sek. After 1 day this inflow falls to about 8 l/sek. With the additional preliminary dewatering lasting 30 days, the initial inflow can be reduced to 15 % only, and with dewatering lasting 90 days to a mere 6,3 %. It is nearly as important to note that similar reduction of inflow rates takes place for the inflows calculated for a later stage.

For the bottom aquifer, which has only to be depressurized, we can define the minimum time needed for the area between the two preparation galleries from which the drilling is performed, to achieve the same level of depressurization as is realized at the bottom of the advance gates where the dewatering boreholes are situated:

$$t \geqslant 9 \times L^2 /(4 \times \quad \times k / S_0) \qquad (8)$$

where S_0 is specific storativity and the other symbols have the previously defined meaning.

It was found out that for the SAKOG-mine conditions at Weilhart the time of depressurization is less than 1 day. Therefore, the bottom wall aquifer will represent no specific problems.

With these developments we wanted to give to the mine designers the tools, which should enable them to define the optimum combination of the length of the long wall and the preliminary dewatering.

EXPERIENCES WITH THE APPLICATION OF SAFETY CRITERIA

After these safety criteria have been applied to the Tarsdorf-Ost area some additional minor water inrushes occurred. For all these inrushes it was found, that the safety criteria were not fulfilled. Of particular interest is one case, where no problems were encountered up to the moment, when the nearby dewatering well was by accident set out of operation. A water pressure build-up followed in the aquifer, resulting in the water inrush. By the time the inrush occurred, the prescribed safety criteria were no more respected. So far, these experiences seem to demonstrate that the criteria, when properly applied, allow for sufficient safety in the mine works.

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