Criteria for Safe Mining under the Surface Water Accumulations in Velenje Lignite Mine

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ABSTRACT

Surface lakes or water accumulation present a possible threat for the flooding of the underground mining works. Therefore, the criteria that define the conditions under which no flooding of the mining works can occur are of vital interest to the miners. The authors present the criteria that they developed for the Velenje lignite mine, Yugoslavia, and that take into account the elastoplastic behaviour of the rocks and the natural stresses involved in the deformable strata between the bottom of the lakes and the mine works as well as the extent of the direct caving-in process resulting from longwall mining activity. Finally a generalization of these criteria to the other rock and stress conditions is discussed.

PROBLEM DEFINITION

As the result of the Velenje lignite mine underground operations, which excavate an up to 166 m thick lignite seam overlain by an up to 500 m thick plioquaternary multiaquifer system by longwall methods with caving or sublevel caving, large surface depressions are being formed. By now, maximum surface subsidence reached nearly 80 m. Those depressions are partly filled with water, thus forming surface lakes. Three lakes exist at the moment, with maximum depth reaching 50 m.

For the excavation under the surface water accumulations, the Salaginov equation was proposed as a safety criteria 20 years ago (2). This equation, defining the safe thickness of the protecting layer between the bottom of a surface lake and the mine works (H) as a function of the depth of mine works (Z), excavation height (m_f), sum of thicknesses of all the hanging wall impervious clayey layers (h_a), and of a given safety factor (f), is:

$$H = 38 \times f \times Z \times m_f / (8 \times \Sigma h_a + 0.34 \times Z) \qquad (1)$$

The permeability, rock stability (with regard to the erosion) and vertical pore pressure distribution changes induced in the areas distorted by the caving process and the land subsidence effects were not clearly understood. Therefore, no clear theoretical justification was found to back the upper equation, especially regarding the safety factor to be applied in the Velenje case. And since the lakes are getting even greater and even deeper due to the contininous mining activity, the mining authorities ordered that this question has to be studied in detail. Either a safety criteria backed on the experimental and theoretical bases has to be developed, or the surface excavations have to be filled up with solid material. Useless to say that the last option would probably ruin the economy of lignite production in the area.

GEOLOGICAL AND GEOTECHNICAL CONTEXT

The Velenje lignite deposit is stretching under the Šalek valley and is 8,5 km long and 1,5 - 2,5 km wide. It is underlying most of the valley's area. This is a typical intermontane lacustrine lignite deposit of pliocene age, with only one, up to 166 m thick productive seam.

For the purpose of this article let us concentrate only on the hanging strata, which are of pliocene and quaternary (pleistocene) age. From the sedimentary point of view they represent sedimentary cycle oscillating from lacustrine to marshy and finally pure terrigenous facies with the continuous intrusions of fan sands and gravels from the north and northwest, where we find more gravels and sands interbedded between silty and clayey deposits. Sands and gravels are progressively pinching out in the opposite directions, to become completely absent in the southeastern parts. Just over the seam lies a clay and silt layer of varying thickness. The more we rise to the surface of the up to 500 m thick series, the more sands and gravels are encountered.

Hydrogeologically, this series represent a multiaquifer system with the individual aquifers of strip like or lenticular (lensy) shapes. In this type of sedimentary environment it is practically impossible to define the individual aquifers regionally. However, due to the fact that these aquifers are more or less hydraulically interconnected through the semipervious strata, a subdivision of the whole series in several subsystems, in which the individual aquifers behave as hydraulically coupled entities, was possible. Basically they are two subsystems - the upper or quaternary, which is practically unaffected by the past dewatering of the hanging wall aquifers, and the lower or pliocene, which is more or less affected by the past dewatering.

Geotechnically, this strata represent loose sediments compacted and consolidated to the state of weak rocks. It was found out that the geotechnical characteristics of the silts and clays are both depth and facies dependent, with facies influence preponderant. From the laboratory data, the limit of plastification of previously unbroken clayey silts lies between 7 and 19 bars, as seen from the following data:

	mean	st.dev.
uniaxial strength	2.459 MPa	1.408 MPa
tensile strength	0.356 MPa	0.193 MPa
limit of plasticity	1.308 MPa	0.621 MPa

For the previously already broken and reconsolidated clayey silts this limit depends on the value of consolidating stress as follows:

consolidating stress	1.9 MPa	3.9 MPa	5.8 MPa	7.8 MPa	9.7 MPa
uniaxial strength	.339 MPa	.513 MPa	.925 MPa	1.261 MPa	1.902 MPa
limit of plasticity	.205 MPa	.355 MPa	.410 MPa	.561 MPa	.820 MPa

The volumetric weight of plioquaternary strata in Velenje valley has a mean of 19 kN/m^3. From the upper results the following relation between the limit of plasticity (LP) and the depth of plastification (DP) can be deduced for the Velenje case :

$$LP = 1.40 \times 10^{-3} \times DP + .042 + .152 \qquad (2)$$

EXPERIMENTAL RESULTS

Land subsidence along large, open cracks is the surface manifestation of the caving-in process. These cracks are in the Velenje case open to a depth of 6 - 8 meters. With depth these cracks get closed, yet the broken or loosened material within the breaking planes was supposed to be more pervious and erosion prone. It was supposed that the water is infiltrating from the lakes into the underlying aquifers along the breaking planes. We checked this supposition by a series of boreholes drilled into the bottom of the lakes. We find out that in a specific area, where no sand layers but only clayey silts exist between the bottom of the lakes and the underlying coal seam, the pore pressure gradient was oriented downwards, but the encountered permeability was not more than 10^{-9} m/s. This was practically identical to the permeability of the undisturbed clayey silts. Where gravel or sand aquifers exist beneath the lakes, their piezometric head was found to exceed the water level of the lakes and therefore no leakage from the lakes into them is possible. The specific question of the permeability of the breaking planes was analyzed by comparing the water levels of the aquifers in the areas affected and unaffected by the caving-in process. If the breaking planes remained permeable after this process occurred, the aquifers positioned face to face on both sides of a such plane should have equal water heads. But we found that this was not true and that the same water heads were found to exist within the aquifers with the same depth under the land surface (or, which is equivalent, the depth under the bottom of the lakes). This is possible only if the subsided parts of the aquifers retained their initial water heads, which leads to the fact that the breaking planes are practically impervious.

DISCUSSION OF THE EXPERIMENTAL RESULTS AND SAFETY CRITERIA

In the case of weak rocks with alternating sands, silts and clays, the subsidence cracks get not only closed with the depth but may even present the areas of diminished permeability.. The question is to what depth remain these cracks or breaking planes disturbed and unsealed and therefore potentially permeable. To answer this, one has to consult the limits of plasticity given previously. By applying the equation (2), it can be shown that the weight of sediments exceeds the limit of plasticity of clayey silts in a depth of 8 metres, which conforms with the field observations of the cracks' opening depth. It is very probable that deeper even during the caving-in process the deformations is only plastic and that no breaking planes ever existed. In that case the water heads of the individual aquifers may show just this and not the breaking plane's sealing. However, mathematical modeling of the caving-in process showed us that some loosening does occur, probably within the sandy layers. For the practical purposes we can drop this discussion and say that for the safety criteria we applied, to remain on the safe side, the lowest experimental result that in the depth of 100 m the plastification limit of reconsolidated clays is .4 MPa (exactly .34 MPa), and much less than consolidating stress of the strata which is 1.9 MPa. If we take into account as the lowest plastification limit the value of .4 MPa, then the depth of the sealing of cracks due to natural stress conditions is 21 m. This is a value containing a safety factor f = 2.63.

For the definition of safety criteria it is important to discuss the possible way in which the water can rush from the lakes into the underground mine openings. For the start of the erosion process, the critical hydraulic gradient must be exceeded. But this gradients, even at the caving-in stage remain very small under the bottom of the lakes. The erosion process can start only from the mine openings upwards, since in the vicinity of the mine openings the caving-in process and the water gradients are the greatest. But in that area, the safe thickness (M) of the protection layer against the hanging aquifers defined in our studies (2) to depend on the thickness of clay layers over the longface cut level with the caving-in process, dependent on the number of previous cuts, height of cut, water pressure on the upper part of the clays and a prescribed safety factor as defined by the safety criteria for the excavation under the water bearing strata in Velenje mine. The values of M were calculated from the stability criterion for the hanging wall beam over the excavation area by the Terzaghi hypothesis of reduced pore pressures and are presented nomogramatically in (2). Since we can not here enter into details, let us say that M is generally for up to several tenths of meters greater than the height of the direct caving-in process that was found to be

$$h = (X+1)_0 * V = \frac{\gamma_p}{\gamma_p - \gamma_r} * V \qquad (3)$$

where are h_0 - height of the caving-in area, measured from the bottom of excavation, V - height of excavation, X - factor denoting the ratio of the caved-in height to the height of excavated area (X=1.5 in the Velenje cave), γ_p - natural volumetric weight and γ_r - splinter volumetric weight. The exact value of M can be read from a nomogram given in (2) as a function of the previously mentioned factors.

On this basis of the upper explained findings, we defined the minimum thickness of hanging wall strata between the bottom of the lakes and the excavation level that is needed for the safe underground excavation under the surface water accumulations to be the sum of the plastification depth of the clayey silts and the thickness of the safety layer prescribed for the safe excavation under the hanging aquifers (M) :

$$T = DP + M \quad (4)$$

CRITERIA APPLICATION

A longface was run with a caving-in method at the depth of 108 m beneath the bottom of a lake, and a 12.5 m high cut by sublevel caving method. The thickness of the intermediate clays was therefore 97.5 m. From the nomogram (1) the value of M = 50 m and therefore T = DP + M = 21m + 50m = 71 m. According to these criteria no water inflow was recorded though the surface deformations and cracks were extremely pronounced. It may be therefore said that the this safety criteria was tested with a safety factor of 1.37.

EXTENSION OF PROPOSED SAFETY CRITERIA TO OTHER MINING CASES

We believe that an extension of these criteria to the other mining areas is possible. In such cases the plastification - depth relation of the hanging impervious strata must be determined and the limit of the plastification of these strata exceeded on the upper boundary of the impervious safety layer, that must be defined according to the extent of the direct caving-in process and the mechanical properties of these strata (layer M, in our denomination).

References

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