Geophysical investigations for the remediation of the karst field storage basin with cover

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Abstract: The storage basin is constructed in location where there was no ponors, but during its test filling water losses were recorded although the storage basin was covered by a clayey carpet. Geophysical investigations have been carried out in order to determine the clayey carpet quality, composition of the Quaternary deposits and predominant groundwater flow.

Key Words: surface storage basin, karst, water losses, geophysical investigation

INTRODUCTION

The Gusić polje compensation basin (Fig. 1) is part of the Senj Hydropower System, used for daily regulation of the natural inflow of the Lika and Gacka rivers. The basin was constructed on the basis of prediction of the satisfactory water holding capacity of the Quaternary cover in that part of the karst field where neither ponors nor suffosions have been found. But the 1965 test filling shown that the water losses were up to 6.4 m^3/s. Additional embankments were constructed inside the basin and the remediation with a clay carpet was undertaken. However, ponors have continued to open and close during repair of the power plant, and water losses are between 0.5 and 1.0 m^3/s.

Several causes for water loss were assumed: poor construction or non-existence of clay carpet in the zone of the channel, or the existence of ponors below the Quaternary deposits. Also occasional moisturizing of these deposits through carbonate bedrock is unfavourable for their stability. For the design of optimal remediation, which should be carried out as soon as possible, geophysical investigations were conducted.

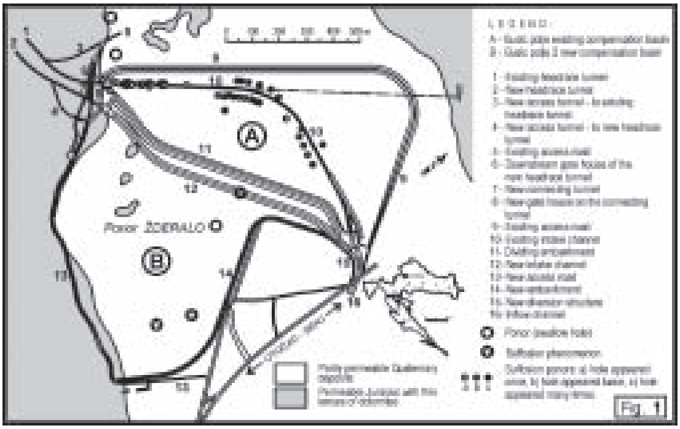

Figure 1. Location map and hydrogeological map of the Gusić Polje reservoir

Scientific paper

Geophysical investigations

The investigation was performed in compensation basin when the storage basin was empty, using geoelectric profiling and resistivity sounding in order to determine the thickness and lithological composition of cover deposits and karstification of carbonate bedrock. Measuring of spontaneous potential was conducted to define the dominant directions of groundwater seepage and zones of water sinking. Self-potential measuring in the basin full of water was planned during the normal work of the plant. Geoelectric methods were chosen because of their speed and of the non-destructive characteristics.

The tectonic structure of the field and the thickness of Quaternary deposits (travertine, clay and calcareous clay) were investigated with a grid of 200 geoelectric sounds with the Schlumberger electrodes arrangement (AB/2=50 m). According to presently available information, new ponors and suffosions occurred in the part of the field where the Quaternary deposits are the thickest, i.e. inside the depressions in paleorelief, as the result of reactivation of old ponors, which had been active before the Quaternary sedimentation. The results of sounding confirmed existence of distinguished palaeodepression in carbonate bedrock and determined its strike. Ponors are connected to the drainage network from the time of palaeodepression formation, which is presently the basis for the groundwater outflow from Gusić field. Smaller ponors appear on the surface outside the deepest parts of the palaeodepression, but they are connected with ponors inside it.

The investigation of thickness and condition of the artificial protective layers was carried out by the geoelectric profiling. According to the design, a protective rock aggregate (15 cm) and impermeable clay carpet (30 cm) were placed over the whole area of the basin. The mud thickness was foreseen to be around 10 cm. Such an arrangement of layers is favourable for geoelectric profiling. Five electrodes spacings were used: 0.25, 0.5, 1.0, 2.0 and 4.0 m. The measurements were performed in 1540 stations set in a rectangular grid, covering the whole area of basin, except the intake canal and its embankments. A computer controlled measuring instrument with Wenner offset electrodes arrangement was used. The average efficiency of 180 measuring points per day was reached, which is significant because of the short period of plant repair. The problem was the thickness of humus sediment (exceeding predicted 10 cm), which slowed down the measuring and decreased expected differentiation of layers during the interpretation.

The results were supposed to single out the zones of damage in rock and clay layers with tendency of forming a ponor. However, the results suggested that the cause of water loss was an incomplete protective carpet on the bottom of the basin and along the central embankments. No low resistivity values corresponding to the clay carpet were recorded in the NE part of basin (Fig. 2). The measured high values were from indigenous travertine cover below the humus layer rather than from protective rock aggregate. As this part of the basin is on higher elevation than the rest and not always impounded, the ponors were not encountered and water probably seeps through the travertine not allowing for further filling of the basin. No resistivities corresponding to the clay carpet were recorded along the inner embankments toe. This corresponds with the facts that the majority of new ponors appeared along the toe of the inner embankments, and that embankments were built before the clay carpet was placed on the bottom of the basin. Such conclusions should be verified through direct investigations.

To determine the dominant directions of groundwater seepage and zones of water sinking, the measuring of spontaneous potential (SP) was carried out during the normal operation mode of power plant with impounded storage basin. Measuring of self-potential was carried out in 1680 locations positioned into rectangular grid (10x20 m). One electrode was used as a reference point outside the basin and the other electrode was lowered to the bottom of the basin. Calculated values of SP showed that the canal is clearly distinguished by lower values of potential and some anomaly minimums. Because the water is above the ground, the areas with minimum values of potential would be the places of sinking of water, which flows towards the areas with maximum values. The anomalies involving particularly low values of potential do not necessarily mean proportional sinking in such locations. On the contrary, it is interesting that greater values are recorded on the inner embankments more frequently than in other areas. This indicates the seepage of water from the surrounding areas towards the embankments. The same is valid for the outer embankments toward which the values of potential increase. The remaining part of the basin shows no anomalies in SP values and recorded values are uniform, which leads us to the conclusion that no new ponors have emerged there.

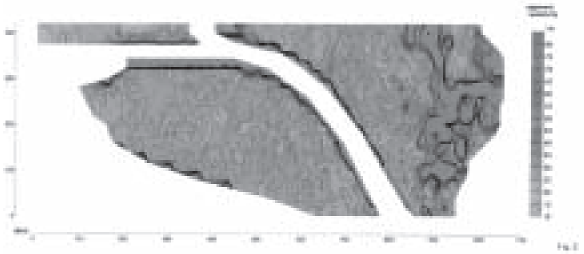

Figure 2. The results of geoelectric tomography for depth level of 1.0 m

We can conclude that the area of increased resistivity follows the area of increased potential fairly well, especially along the north edge of the basin. There, the zone of low resistivity, extending like a narrow band, is identical to the local minimum of self-potential. Consequently, the locations of high resistivity are the zones towards which the groundwater flows, probably through the surface layer. This confirms the presumption that the clay carpet was not constructed in that area.

Due to the increase in installed Senj HPP discharge, an impoundment of a new compensation basin in the part of the field outside the present basin with similar hydrogeological conditions, was considered as an alternative solution. The refraction seismic method was used to determine the thickness and lithological composition of the cover, as well as the condition and karstification of carbonate bedrock in the future basin.

The whole field was covered with 135 spreads of 110 meters, set in 21 profiles, with station interval of 10 m and shot point every 6 stations. That enabled the investigation depth of 40 m (expected thickness of cover up to 20 m). During the investigations, two distinctive problems appeared. An unexpected seismic noise in some parts of the field was probably caused by the flow of groundwater through the travertine. The second difficulty was an outstanding damping of seismic energy, most likely in silty travertine layer, which has a small degree of lithification, and consequently poor elastic properties.

The seismic refraction data were interpreted by critical distance method. On the basis of the sesmic interpretation and geological model, the underground was separated into four layers: the heterogeneous overburden complex, the Quaternary deposits mainly consisting of clays, the weathered rock and the basic carbonate rock massif. The seismic refraction results did not trace existence of the palaeodepression in carbonate massif underneath the new basin. Also it was not possible to positively define spreading of shear or fault zones in the bedrock. For further analysis, the maps of field with the results of refraction seismic were created. On the surface complex thickness map (Fig. 3) the potential places for formation of the suffosions are marked. On the map of the deposit thickness above the carbonate rock two sectors shaped like channel coincide well with region of low velocity on the map of P wave velocities in the upper part of the basic rock. The anomaly zones are verified with the borehole next to the recently active ponor on the surface.

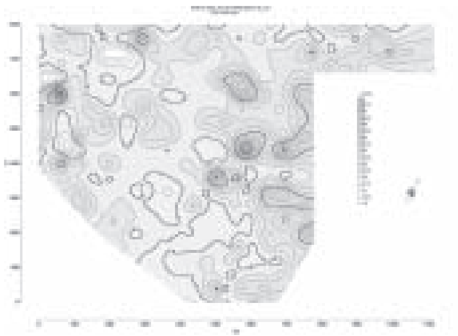

Figure 3. Map of the surface complex thickness

CONCLUSIONS

It was determined that the most intensive seepage was in the area of the canal, which is covered with concrete slabs under which no protective clay layer was constructed. Since the investigations inside the basin can be conducted only during the annual one-month power plant overhaul, the solution was chosen for remediation of the canal area, which can be performed in stages over a period of several years. The economic and technical comparison of various possible solutions led to the choice of a method that includes construction of a protective impermeable cover of the canal made of foil laid on a geotextile layer. In the areas inside the basin, where investigations determined the possibility of water loss or discontinuity of a clay carpet, a new clay carpet or the strengthening of the existing one is foreseen. The envisaged scope of works is planned to be performed in a two-year period during an annual interruption of the power plant work.

For impoundment of surface basin in the karst field, the water holding capacity of which depends on impermeability of the Quaternary deposits, one should take into account the stability of the this cover. Therefore during the preliminary design stage it is necessary to carry out extensive investigations in order to learn about the genesis of the ground, hydrogeological relations and hydrological conditions that were present during the formation of the field, as well as after the sedimentation of Quaternary cover. Besides surveying boreholes and measuring groundwater tables, it is necessary to perform geophysical investigations to estimate the thickness and lithological composition of the cover, as well as the condition and karstification of the carbonate bedrock. To solve the problem of the water holding capacity of the basin and remediation of losses through suffosions in already existing basins, the geoelectric investigation methods have proved to be suitable under the conditions of exploitation when the investigation time is limited and the bottom of the basin is covered with soft deposits. It should be emphasized that the biggest problem for realization of the water holding capacity of the surface basin in the karst field is the stability of the bottom of the basin, because the water holding can be solved with artificial materials, but no permanent solution for undisturbed exploitation of the facility can be achieved without stability of the foundation.