Monitoring of an earth-rockfill dam and proposing revitalization measures based on interpretation of monitoring data

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Abstract

There are more than 40 large dams in R. N. Macedonia, most of them designed and built in the 1950-the 60s. Many are earth-rockfill dams: several are located in the south-eastern part of the country and their accumulation of water is proposed for irrigation and water supply of the nearby towns. These are characterized by a well-established monitoring system, consisting of piezometers, pore pressure and total pressure cells, water outflow from the sources, visual observation and surveying measurements. These are regularly followed by a public enterprise and later interpreted by the Chair of Geotechnics at the Faculty of Civil Engineering in Skopje, due to which commitment valuable documentation in chronological order is prepared. As such, in 2013, it was noticed that some of the piezometers at one of these dams have shown unexpected variation in the groundwater level while wetting on the bench of downstream slope and seepage at the groin was registered. This was an alarming signal to immediately realize decreasing in the water level and to conduct detailed geotechnical investigations, consisting of field and laboratory tests, and data analysis. Based on findings from these works, revitalization measures were proposed later which are focused on the construction of grout curtains which would result in improving the permeability of the dam body. The paper aims to present the results from the monitoring of the dam since 1994 and discuss the measures taken for its revitalization as a result of data interpretation, most of which are realized meanwhile.

Keywords: Dam, Monitoring, Piezometers, Investigation, Revitalization.

1. Introduction

This paper presents the results from the monitoring of the Vodocha dam in R.N.Macedonia since 1994 and the measures taken for its revitalization as a result of data interpretations. Vodocha is earth- rockfill dam without grout curtains, built from 1962-to 1965 for irrigation of 3100 ha since 1966 and water supply of Strumica town. The main goal of the monitoring is to obtain confidential data for assessment of the condition of the dam at each moment, take appropriate measures if necessary, and exclude any risk. In 2013, after heavy rainfall events, some of the piezometers show unexpected variation in the groundwater level, wetting on the bench of the downstream slope, and seepage at the groin. This was a reason to immediately propose decreasing the water level slowly and to make a detailed geotechnical investigation and data analysis. Revitalization measures were proposed in 2015 which are focused on the construction of grout curtains to improve the permeability of the dam body.

Figure 1: Downstream and upstream slope of the dam.

2. Monitoring

The monitoring system consists of visual observation, piezometers, pore, and total pressure measurements, water outflow from the sources, and surveying measurements.

In addition, the water level in the reservoir and the flowing waters are measured. The Monitoring Program defines the methods and procedures, the number and type of instruments and equipment, the layout of the measuring points, the measurement scope and dynamics, as well as the criteria for evaluating the allowed changes in the measurements.

The horizontal displacements of the dam are monitored through geodetic measurements of the changes in the position of the markers built into the body of the dam. Figure 2 presents the marker position and the maximal horizontal displacement through the years.

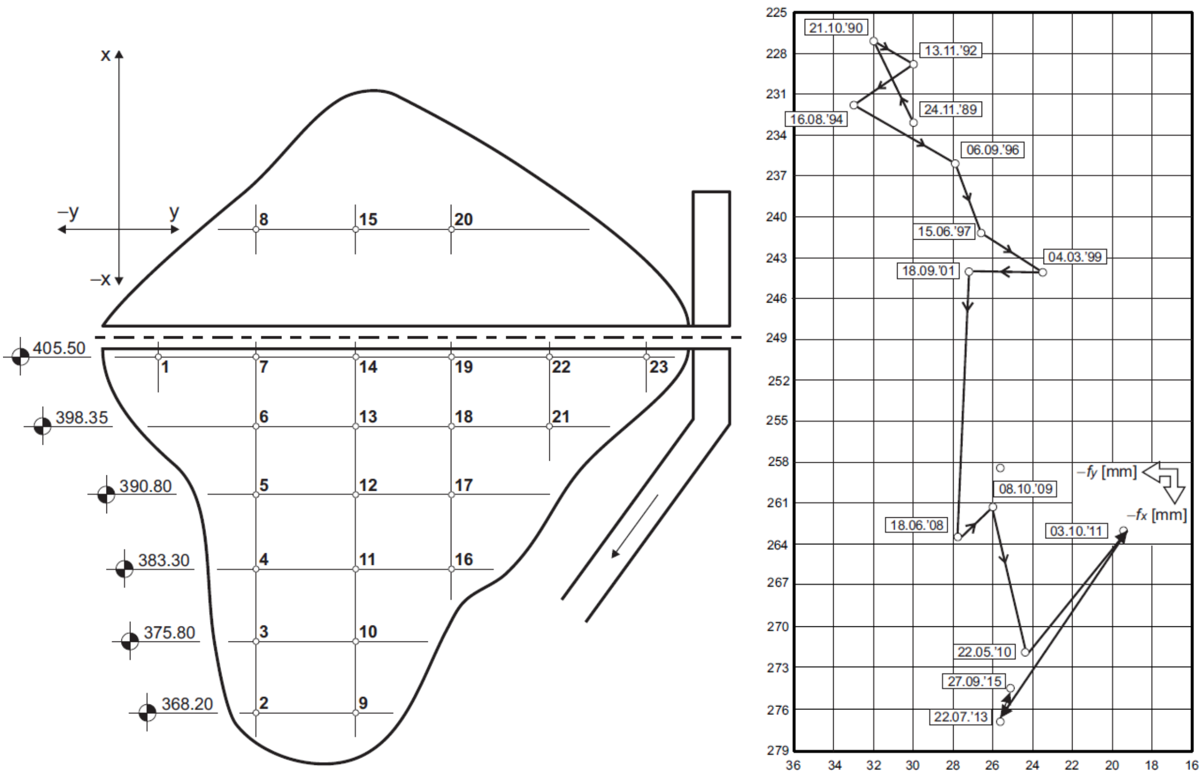

Figure 2: Marker position and the maximal horizontal displacement of the marker 19.

According to the performed measurements, the horizontal displacements of the markers on both slopes show small gradual changes directed towards the middle of the dam. The displacements along the y-axis are directed from the sides to the middle, while in the direction of the x-axis i.e. in the direction of the slopes, the maximum horizontal displacement measured so far is 274.8 mm in the mark 19.

The vertical displacements i.e. settlements of the benchmarks on the downstream slope are also measured. The largest settlement is achieved at the middle of the dam crown on both downstream and upstream slopes (on the profile from markers 9 and 15). The intensity of the changes indicates decreased rate. The vertical and horizontal displacements are within the limits provided by the Auscultation Project.

The changes in the groundwater level are monitored with 13 piezometers at intervals provided by the annual Monitoring Program. The layout of the piezometers is given in Figure 3.

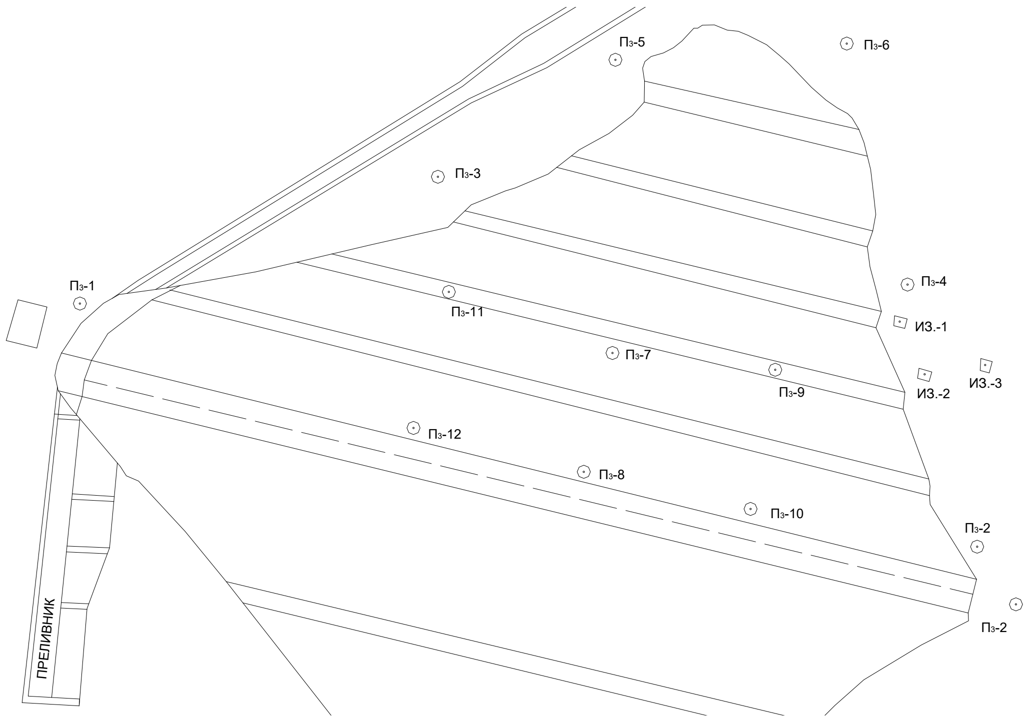

Figure 3: Piezometers and sources layout.

in most piezometers, the water level minimally oscillates (Figure 4). The water level in the piezometer P3 varies in correlation with the water level in the reservoir. After the inspection in 2013, an unexpected variation of the water level in piezometer 8 was noticed from February to June, which is probably related to the reservoir water level variations. After that more often measures were taken to better understand the condition of the downstream slope and to define the causes leading to wetting on the downstream slope.

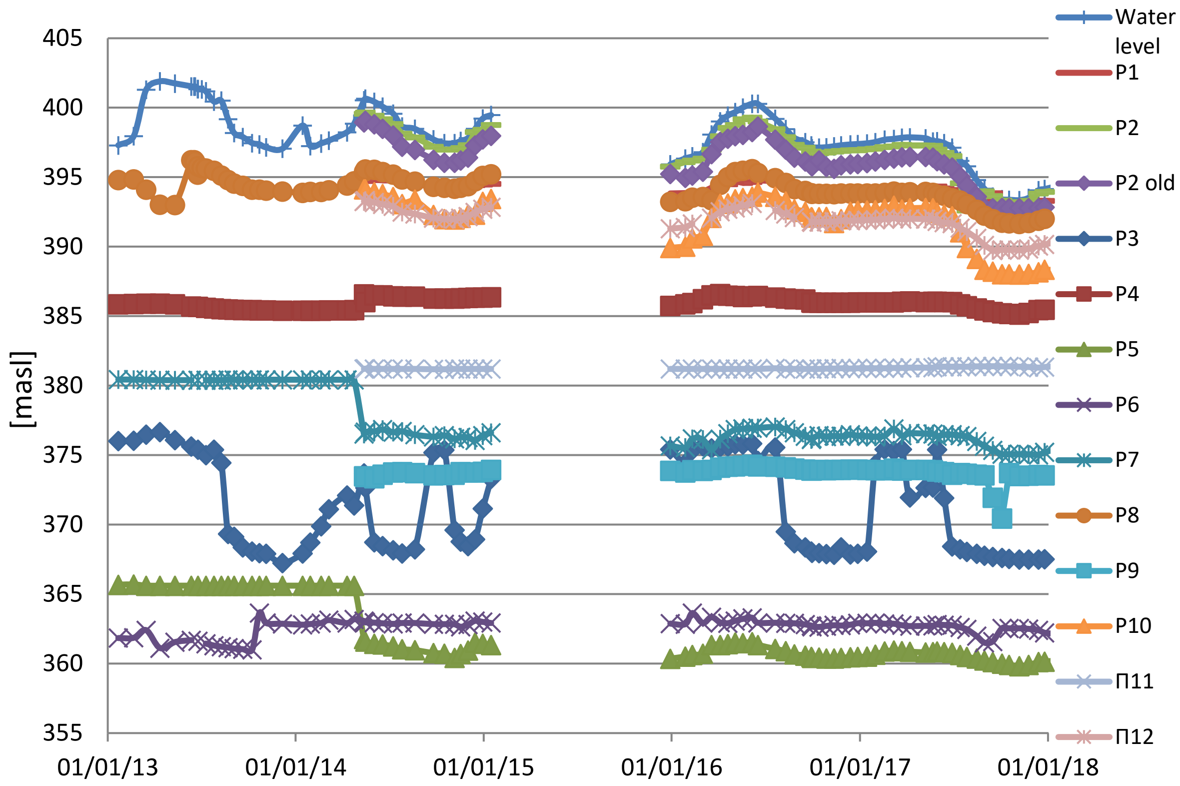

Figure 4: Groundwater level variations for 5 years

2.1 Phenomena and processes description

Visual monitoring of the dam and reservoir covers all possible manifestations of changes in terms of dam profile changes, slopes, surrounding terrain and reservoir banks. In 2013, wetting of bench 3 on the downstream slope (382.50 m a.s.l.) and spring water flow were observed. A line erosion with an open gully along the dam contact with the right groin was also observed. There was water retention on the dam crown with the possibility of infiltration in the downstream zone (Figure 4).

Figure 4: Wetting on the bench, gully on the right groin, sources and water retention on the dam crown.

The change of water flow through the dam on the downstream slope is monitored in the springs No. 1, 2 and 3 Most of the time it is leakage water, but when the water table in the reservoir is above 397 masl, there is increased flow. The results from the monitoring are shown in the following diagram.

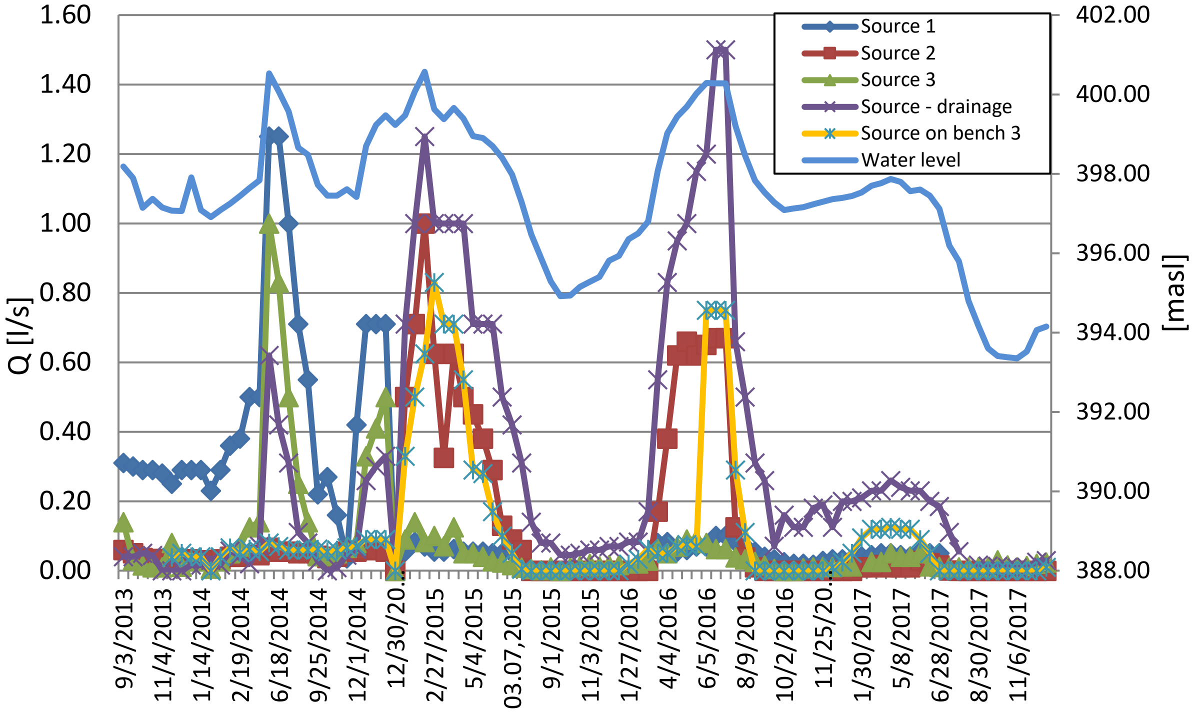

Figure 5: Spring flow variations for 5 years.

The water flow through the springs is directly related to the water level in the reservoir. For a maximum water level in the reservoir of 400 masl, the water flow rises above 1.0 l/s. Until the realization of the revitalization measures of the dam, the water level in the accumulation is kept relatively low.

Based on the above, it can be concluded that the wetting and water flow on the downstream slope most likely occurs through the body of the dam through already formed concentrated filtration flow paths, which are diffusely manifested on the surface of the slope.

3. Geotechnical investigations

The manifestations of the dam indicate that there is a need to undertake more comprehensive technical revitalization interventions, for which it is necessary to have appropriate geotechnical data. The main goal and task of these geotechnical investigations were to check and define the condition of the dam body in the downstream part through the current and comparative values of the properties of the materials which are essential for the analysis and dam safety.

The main data on the geological-geotechnical properties of the current terrain along the dam site and reservoir are known from the rich investigations performed in 1960/61. The first investigation program includes 7 geotechnical boreholes along the dam axis with a total depth of 268.00 m', 4 investigation boreholes on downstream profile, 8 investigation galleries of different lengths; 8 trial pits; 8 piezometers on the sides of the valley and part of the dam body, but also investigation works for borrow pits for natural local construction material (schists, clay, filter gravel and limestone). The investigation work in 2014 includes 6 geotechnical boreholes with a total depth of 123.50 m'. These boreholes are used as new piezometers. During the investigations, Luegon and Lefranc tests were conducted to obtain the permeability which leads to an innovative permeability map of the dam and draw the wetting zone.

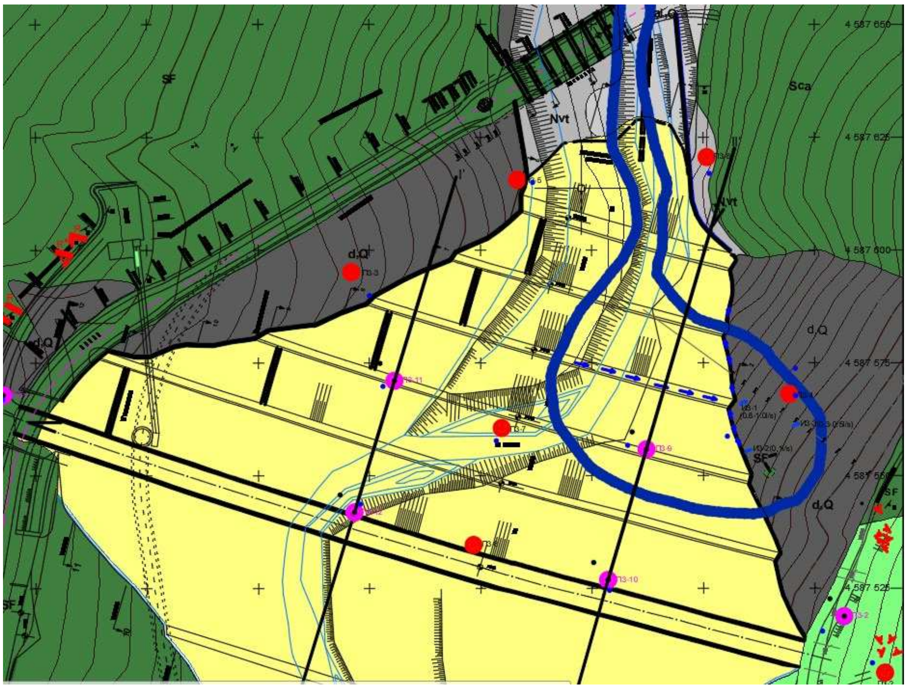

Figure 6: Layout of the wetting zone

From the investigations, it can be concluded that the geological conditions at the right base of the dam are very unfavourable (appearance of many cracked limestones with extremely increased water permeability) and with the absence of a grout curtain, there is direct infiltration of groundwater under and around the dam. This was confirmed by the appearance of springs on the right dam side after filling the reservoir. The grain size distribution of the material in zone 1 defines it as GFc, GFc/SFc with the permeability of K_f=n.10^{-4} – n.10^{-3} cm/s, double increased moisture content, decreased compaction. There is also a possibility of suffusion and water transport through the investigation gallery for which there is no information about its condition. Assuming practically impermeability of zone 1 of the dam body, there is a high probability that the groundwater under pressure transfers to the zone 2 through the extremely permeable rock masses – limestones and the contact with the schists, which can be one of the reasons for the appearance of water on the downstream slope.

4. Revitalization measures

Generally, it is not allowed the occurrence of any wetting or leakage of water through the dam body is the first sign of urgent action to revitalize such phenomena.

One of the possible technical solutions for revitalization is the construction of waterproof protection (geomembrane) on the upstream slope of the dam, properly "anchored" from the base rock to the dam crown. Another solution can be a clay-concrete diaphragm from the dam crown by injection into the base rock mass for prevention of infiltration under the dam or jet grouting in the dam and the dam base. All these solutions can be financially irrational because some require emptying the reservoir, proper capture of river water, and removal of the accumulated sediment in the area of the foundation of the upstream slope, so the user will not be able to use the water for several seasons. From a technical and economic point of view, the solution of grout curtain made by classical injection in the zone with the most unfavourable water permeability seems to be the most rational solution (Figure 7).

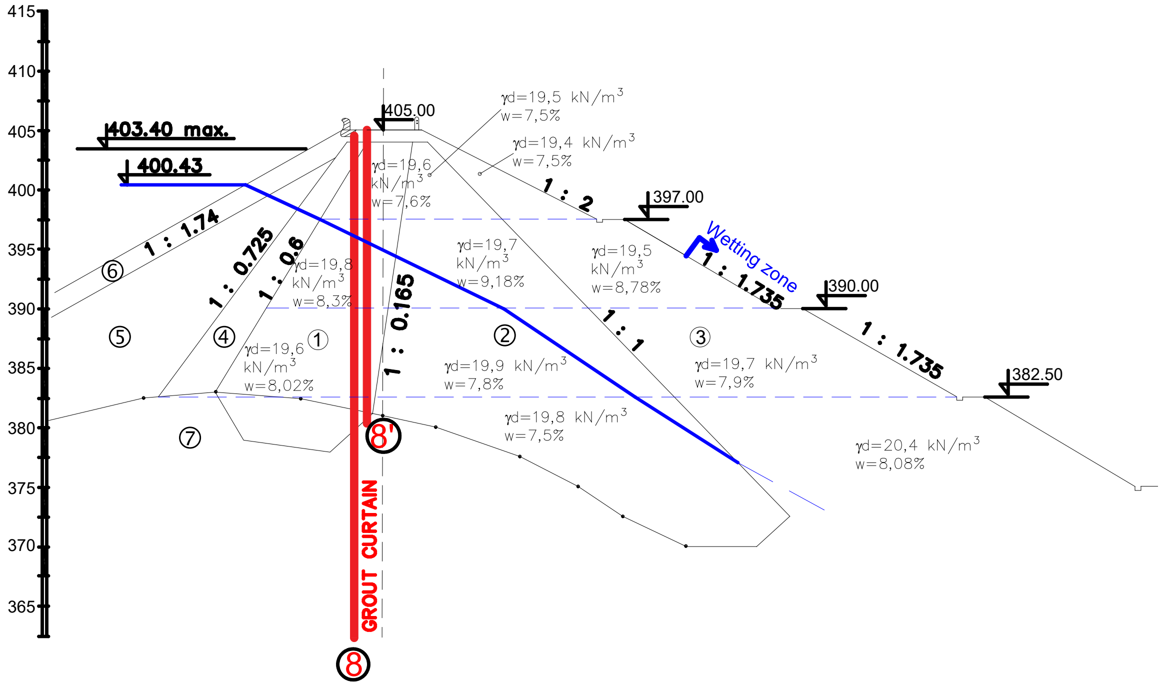

Figure 7: Dam cross-section: (1) impermeable core, (2 and 3) rockfill, (4) inclined filter, (5) stone part, (6) coarse stone coating, (7) base and (8 and 8' in red) two-row grout curtain.

The main task of the grout curtain is to reduce the filtration of water through the rocky environment, the dam body, as well as the contact between these two environments; preventing the formation of concentrated groundwater flows and suffusion, primarily in the dam body, which can directly contribute to the deterioration of the general stability (through reduced compaction, increased moisture content, reduced strength parameters of the embankment material, etc.); improving soil and rock parameters and decreasing the uplift capacity of the base. It is also expected to fill the pores in the zones with slightly increased water permeability which would achieve the required effect.

Regarding the dam body, the curtain belongs to a part of the deep and right side curtain. Deep down, the curtain in the base rock is brought to a practically impermeable environment with a water permeability ≤ 3 Lu. A two-row grout curtain is designed in the dam body due to the character of the material, while a single row is in the basic rock mass. The order (upstream and downstream order) implies time-independent construction in two phases. So the curtain has an investigative, current and controlled character. A bentonite-cement mixture is provided for the grout curtain.

In addition to these measures, additional interventions are designed, such as the extension of the wave wall and the spillway zone, and the repair of the crown base and the stairs at the benches.

4. Conclusions

The long-term monitoring of the Vodocha dam provides confidential data for assessing the condition of the dam at any time. Based on the monitoring data and the analysis of the presented results, it can be concluded that the dam in the current period of operation has undergone certain changes resulting from the consolidation process, the impact of accumulated water, and dam-atmospheric interaction.

In 2013, after heavy rainfall events, some of the piezometers show unexpected variation in the groundwater level, wetting on the bench of the downstream slope and seepage at the groin. For a maximum water level in the reservoir of 400 masl, the water flow rises above 1.0 l/s. The water flow through the springs is directly related to the water level in the reservoir indicating that over time concentrated filtration flow paths are formed which are diffusely manifested on the surface of the slope.

This was a reason to immediately propose decreasing the water level slowly and to make a detailed geotechnical investigation and data analysis, which specify the reasons for the established manifestations. It was concluded that the geological conditions at the right base of the dam are very unfavourable (appearance of many cracked limestones with extremely increased water permeability) and with the absence of a grout curtain, there is direct infiltration of groundwater under and around the dam. This was confirmed by the appearance of springs on the right dam side after filling the reservoir. Assuming practically impermeability of zone 1 of the dam body, there is a high probability that the groundwater under pressure transfers to the zone 2 through the extremely permeable rock masses – limestones and the contact with the schists, which can be one of the reasons for the appearance of water on the downstream slope.

Revitalization measures were proposed in 2015 which are focused on the construction of grout curtains from bentonite-cement mix to improve the permeability of the dam body. The curtain has an investigative, current and controlled character. A two-row grout curtain is designed in the dam body due to the character of the material, while a single row in the basic rock mass to the practically impermeable environment. The order (upstream and downstream order) implies time-independent construction in two phases. This solution is considered to significantly improve the condition of the dam and reduce the risk of instability.

Finally, it may be recommended that innovation in monitoring equipment and instrumentation is required to monitor changes in the future in a more detailed and accurate manner.

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