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ANALYSIS OF SEEPAGE CONTROL AND SLOPE STABILITY OF THE “VRANJAŠ” EMBANKMENT DAM

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ABSTRACT

The main characteristic of embankment dams is their constant contact with water. Since water flows through pores of permeable soil, there is a tendency of rinsing particles of building material of the structure and possibility of slope failure to decreased weight caused by the action of hydrostatic stress. Eventual failure of such structures would cause enormous consequences and therefore, their stability must not be jeopardized. Accordingly, this paper focuses on the analysis of seepage control and slope stability of the “Vranjaš” embankment dam. As the built structure does not comply with the design, comparison of the results obtained from the analyses for previous two cases was conducted. The GeoStudio software package was used in calculations. It is among the most common software programs used in the field.

1. Introduction

Embankment dams are among the earliest water management structures. They are built mostly from the ready availability of earth and rock materials by laying out and compacting layers of material. Due to the porosity of the materials they are built from, these structures are highly vulnerable to suffusion i.e. the mass movement of fine particles driven by seepage forces, which can initiate internal erosion and instability of the structure. In addition, the structures are highly vulnerable to overflow, which can lead to complete or partial failure of a

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structure [1, 4, 5]. Given the significance and the function of dams, their stability may not under any circumstances be jeopardized.

The "Vranješ" embankment dam seepage control and slope stability are analyzed in the paper. The GeoStudio software package developed by GeoStudio International, Canada, was used in the analysis. The package is comprised of eight programmes designed for the analysis of pervious soil. The following programmes were used: GeoSEEP/W – for the analysis of seepage through the embankment and GeoSLOPE/W – for the slope stability analysis [2].

2. Brief Description of the Structure

The "Vranješ" dam is located on the Fruška Gora southern hillsides nearby the settlement of Manđelos in the Republic of Serbia [3]. It was built in 1972 to collect water for irrigation purposes, erosion protection, flood wave hindering and water supply to certain areas. The total capacity of the reservoir created by the dam equals 675,000 m^3. The primary utility of the dam is the protection against flood wave above the settlement, given the significant stormwater quantities and the configuration of the surface. Prior to the dam construction, stormwater used to produce streams that flooded and put at risk the surrounding areas and settlements. This issue was resolved with the dam construction.

The total crest length is 224 m, whereas the crest is 3 m wide. The total height of the dam is 13,9 m including the height of 7,5 m above the ground level. The crest elevation is at 117 m. The volume of earth fill in the embankment is about 34,000 m^3. The upstream slope and the downstream slope equal 1:2,5 and 1:2,25, respectively. Six boreholes were made on the site to determine the soil structure.

3. Analysis of the Seepage Line Through the Embankment and Estimate of the Soil Stability

3.1. Analysis of the Seepage Line Under the Existing Conditions

The calculation is made for the dam built from a homogenous material on permeable soil. The analysis was made for the largest cross section shown in Fig. 1. The concrete face is made up to the elevation of 115,5 m, which leaves unconfined space of 0,5 m for water to penetrate into the embankment of the dam. A horizontal drain at the downstream slope is 13,5 m long. The dam is founded in the soil layer with the coefficient of permeability of $K = 1{,}4\times10^{-7}$m/s with the soil layer with the coefficient of permeability of $K = 5\times10^{-9}$m/s underneath it. Fig. 2 shows details of the filter and the basement of the concrete face. The filter is made of 50 cm thick gravel layer (Fig. 2a). The middle part of the 20 cm thick filter layer is of larger fraction. The finer fraction is covered with geofilm. The concete face rests on a concrete beam, below which is a layer of gravel (Fig. 2b). The required parameters of the materials are given in Tab. 1.

Table 1. Parameters of the materials

	Unit Weight	Cohesion	Phi	Coefficient of permeability
The dam core	18,2 KN/m^3	10 kPa	20°	$2{,}07\times10^{-9}$m/s
Top layer of terrain	17,0 KN/m^3	5 kPa	22°	$1{,}40\times10^{-7}$m/s
Bottom layer of terrain	17,5 KN/m^3	8 kPa	20°	$5{,}00\times10^{-9}$m/s

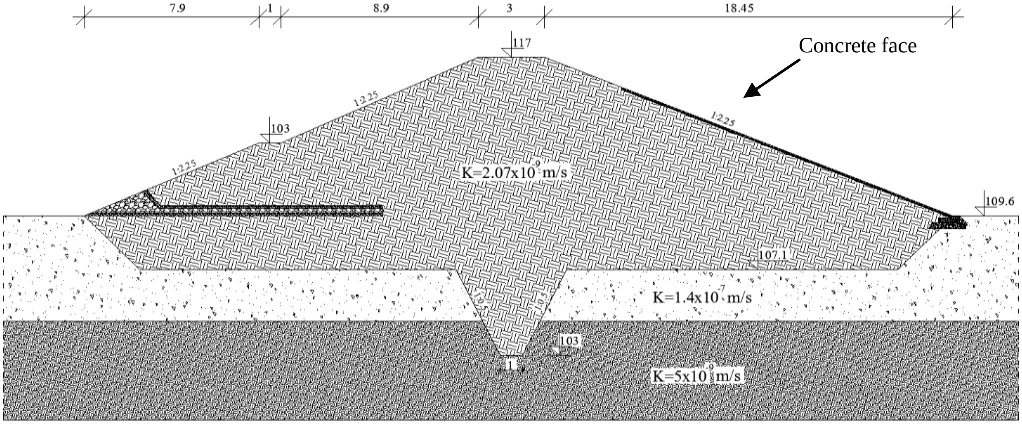
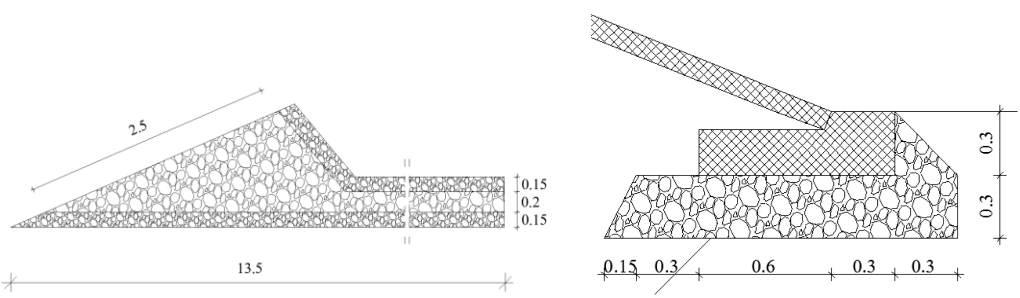


Figure 1. The dam largest cross section



(a)

(b)

Figure 2. Structural details of the dam cross section – filter (a), basement of the concrete face (b)

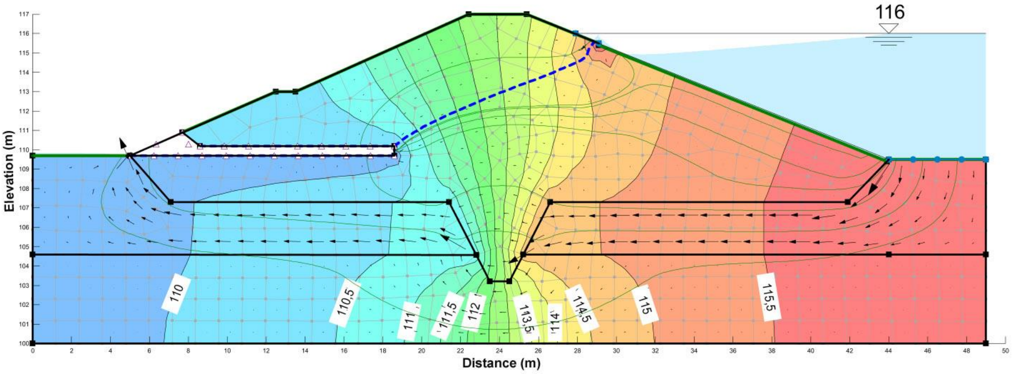


Figure 3. Seepage line shape and potential heads under the existing conditions

The blue dashed line is the seepage line. Under the existing conditions, water inflow above the concrete face is a concern. In this way the equipotential lines are elevated but this has no significant effect on the dam stability due to the long drain. The green lines indicate paths of droplets, whereas arrows show flow vectors. The arrows in the first soil layer look more dense and longer. This indicates higher conductivity due to the higher coefficient of permeability. The order of magnitude 100 is lower than the conductivity of the dam core and the bottom layer. The cut-off trench made in the dam core serves to provide resistance to water flow through the first layer of soil and thus reduces the flow underneath the dam. The calculated flow rate for the first layer of soil equals $2{,}09\times10^{-8}$ m^3/s/m’, whereas the flow rate through the dam core equals $0{,}3\times10^{-8}$ m^3/s/m’.

Hydraulic gradient to initiate suffusion would be 0,631. The critical hydraulic gradient was calculated from empirical expressions [6]: by Zihard, Abramov, Kovacs but also from the Istomina’s graph. The obtained values indicate no risk of suffusion or liquefaction within the dam core.

3.2. Analysis of the Seepage Line for the Design Conditions

The concrete face on the upstream slope of the dam was not constructed following the design. The design provided for the concrete face along the entire upstream slope of the dam but it was only made up to the elevation of 115,5 m. Failure to comply with the design has increased values of pore water pressure, thus leading to higher flow rate and higher seepage line. As the slope stability largely depends on pore water pressures, this also decreases the value of the slope safety factor. Given that the dam rehabilitation and the concrete face extension to the dam crest are designed, the analysis was also made for the design conditions. The result of the analysis is shown in Fig. 4.

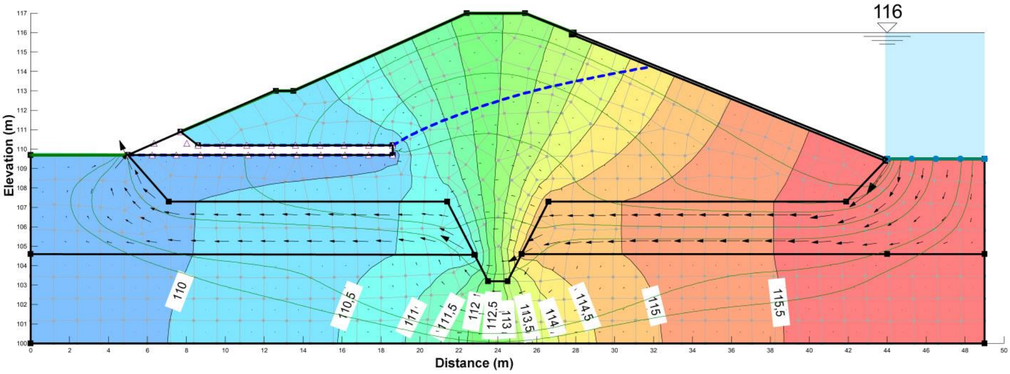


Figure 4. Seepage line shape and potential heads for the design conditions

Comparison of the seepage lines for the existing conditions and the design conditions indicate significantly lower line that is, the potential head has decreased. The concrete face is watertight and provides resistance to water flow. Seepage is now initiated at the most downstream point, thus increasing the seepage path length (green lines). As the value of the potential head is inversely proportional to the length of the seepage path, the potential head that is, pore water pressures are reduced. Given that the values of pressures for the design conditions are lower than the values of pressures for the existing conditions, there is no risk of suffusion or liquefaction under the design conditions.

4. Analysis of the ”Vranjaš” Dam Slopes Stability

4.1. Analysis of the Slope Stability Under the Existing Conditions

The GeoSLOPE/W software package was used to check the slope stability. The calculation was made for the specific cross section. The Morgesten-Price method was used to determine the critical slip surface. Values of pore water pressures were taken from the completed SEEP/W calculations. The case with the existing conditions was analyzed since the values of pore water pressures are higher than their counterparts under the design conditions. Given that traffic is allowed on the dam crest, the surcharge load of 35 kN was added into calculation, which would simulate the load of the heaviest vehicle applied on the dam. Fig. 5 shows the critical slip surface that is, the slip surface with the lowest calculated factor of safety of 1,7. As the minimum required value of the factor of safety is 1,2, it can be concluded that there is no risk of the upstream slope failure.

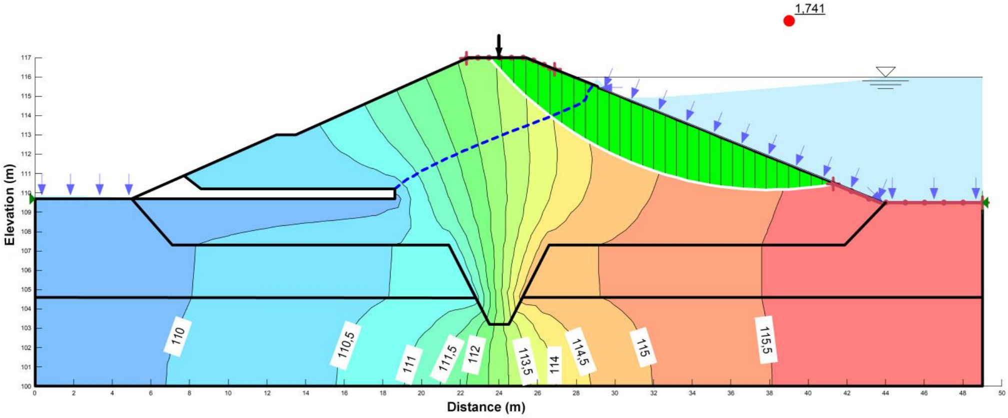


Figure 5. Shape of the critical slip surface under the existing conditions

4.2. Analysis of the Slope Stability Under the Existing Conditions with Rapid Drawdown by 2 M in the Reservoir

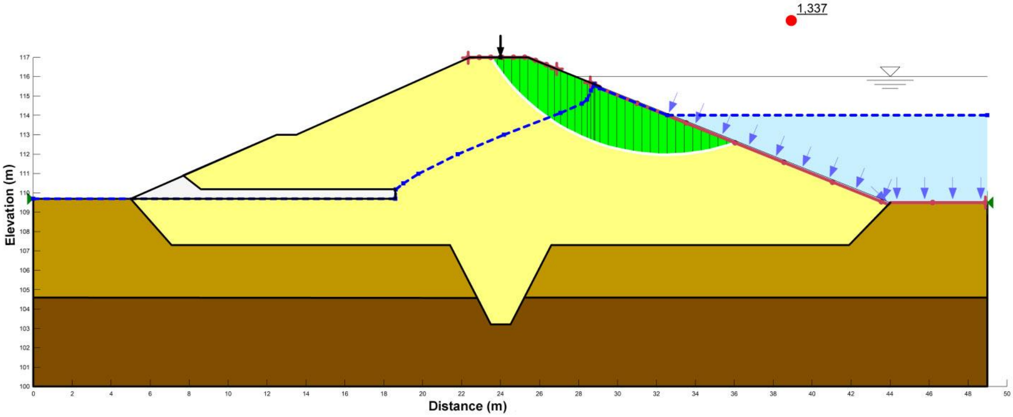


Figure 6. Shape of the critical slip surface with rapid drawdown in the reservoir under the existing conditions

Exploitation of water in the reservoir may cause rapid drawdown of the water level. In such case, rapid drawdown would not allow pore water outflow, thus keeping it confined within pores for a certain time. Accordingly, the pressure inside the dam core remains unchanged whereas hydrostatic pressure applied on the upstream slope is decreased. It has been determined based on the exploitation of water in the reservoir that the water level can rapidly drop by 2 m that is, from the elevation of 116 m to the elevation of 114 m. Fig. 6 shows the critical slip surface for the given case. Shear strength coefficient is about 1,33, which is higher than 1,2, indicating that there is no risk of the slope failure.

5. Conclusion

Embankment dam designs require a deep insight into the slope stability taking into account possible serious consequences caused by slope failures. In addition to static stability required for any structure, seepage processes and slope stability also require particular analysis with embankment dams. For seepage processes, suffusion and liquefaction should be analyzed regarding the material of the dam embankment and the foundation soil as well as the effect of pore water flow. Therefore, the material properties should be carefully identified and the flow regime within the embankment and the surrounding soil determined.

A particular case was analyzed in order to illustrate the calculation used to determine the impact of the processes in question. Stability of the “Vranjaš” dam was analyzed. The GeoStudio software package was used in the analyses. First, GeoSEEP/W programme was used to determine the seepage line shape and then, GeoSLOPE/W programme was used to determine factor of safety for the slope shear strength. The dam section with the largest cross section was analyzed because stability of this section of the dam would provide stability of the rest of the dam.

The existing conditions were analyzed first. The results show that critical values that can initiate suffusion and liquefaction are significantly higher than the actual values of critical hydraulic gradients for suffusion and liquefaction. In addition, factor of safety to shear stress is higher than the required value, thus providing this form of stability. Given that the existing conditions are different from the design conditions, the design conditions were also analyzed. The results illustrate how these two conditions are different. The analyses show how the concrete face affects the values of pore water pressures in the dam embankment and the foundation soil. The concrete face is watertight and resists water flow, which results in the loss of potential and decrease in potential head. This, in turn, affects the values of pore water pressures and the increase in factor of safety. A rapid drawdown in the reservoir can be a serious concern with embankment dams. Accordingly, the case of rapid drawdown by 2 m was also analyzed. The results show distribution of pressures and significant decrease in the factor of safety. It has been determined that this case can be considered applicable in the analysis of slope stability.

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