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VERIFYING THE OPERATIONAL SAFETY OF SOME EARTH DAMS USING OWN CODED COMPUTER PROGRAMS

BY

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Abstract. The analysis of a dam operation safety as well as of other hydrotechnical constructions involves a hydraulic and structural technical expertise. Over time, changes of operational parameters for some dams result in changes of their structural and hydraulic behavior. We have studied such a case using our own designed software for checking the present seepage situation and the slope stability of an earth dam. The obtained results revealed the new safety parameters of the dam and leaded to new solutions for controlling the hydraulic erosion phenomena.

Key words: operation; safety; earth dams.

1. Introduction

Some of the functions and parameters for which hydro-technical works were initially designed can modify over the years. The social and economic changes, which occurred in Romania after 1989, have in some cases determined

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the partial modification of the functionality of some hydrotechnical systems. Some hydrotechnical works undergoes new demands, not initially taken into consideration, while designing. This situation is reflected in the safety of operating the system while introducing supplementary risk factors. Generally speaking, the operation safety of a hydrotechnical construction is analyzed through a hydraulic and structural technical assessment (Hobjiă & Luca, 2000; Stematiu & Constantinescu, 1998). An analysis of the system's response in the new situation enables the discovery of new risk parameters and the stating of the necessary safety measures while operating the system.

An analysis of this type has been carried out on the Varsolt Hydrotechnical System, located on the Crasna River in Romania. The results of the test have contributed to the rehabilitation and modernization of the earthen dam (Expertiza tehnică…, 1997).

2. The Characteristics of the Dam

The Varsolt Hydrotechnical System is located on the Crasna River in northern Romania and lies 96 km away the border with the Republic of Hungary. The accumulation was designed with the purpose of reducing flood waves with a probability of overflowing of 1% (verified for 0.1%), irrigation, fish farming and water supply for a downstream town. The hydrographic basin corresponding to the accumulation measures 310 km^2. The hydrotechnical system started to be exploited in 1979. In the later years the hydrotechnical system underwent several structural and functional modifications (Expertiza tehnică…, 1997).

The storage lake is achieved through a frontal dam with a heterogeneous structure executed with local materials. The construction parameters of the dam are: maximum height, 14.0 m, width at the crest, 5.0 m, length, 2.160 m, average width of the road territory, 80.0 m, etc. (Fig. 1). The storage lake specific lakes are: on the total, 46.2 million m^3, accumulated, 39.86 million m^3 at the maximum level of exploitation (p = l% and elevation 243.94 m B.S. (Black Sea), the mitigation volume for flood waves, 24.00 million m^3, etc.

The calculus discharges are: the design discharge $Q_{1\%}$ = 330 m^3/s and the verification discharge $Q_{0.1\%}$ = 516 m^3/s. The flow absorbed from the basin for water supply is Q = 0.75 m^3/s. The upstream face of the dam is described by two slopes and is protected by a layer of riprap (in the initially designed slope was 1:3.5 with a concrete slab protection). The downstream face of the dam has 1: 2 and 1: 3.50 slopes, with two berms having 2.0 m width, located at the elevation of 239.50 m and 234.50 m, respectively. The downstream slope presents a drainage system.

The dam is founded on the alluvial deposit of the Crasna River. The deposit presents a layer of argillaceous soils at surface with a width of 2.0 to 6.0 m, under which there is a layer of sands and rubble with a width of 2.0 to 5.0 m. The fillings within the dam's body are executed from an irregular alternation of argillaceous soils and, locally, argillaceous sands. Locally, within the dam's body, there are areas of sands alternated with rubble.

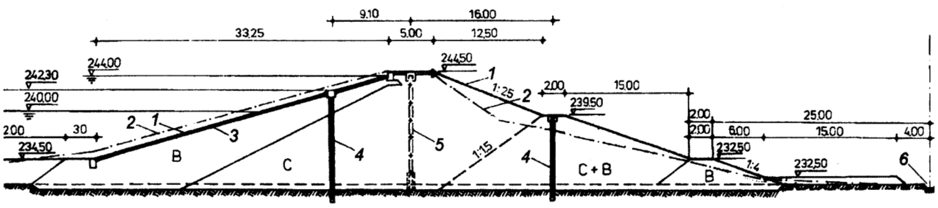

Fig. 1 – The transversal profile of the Varsolt dam: *1* – the initial shape; *2* – the present-day shape; *3* – pitching of the concrete slab; *4* – piezometer tubes; *5* – mark of depression; *6* – channel.

The water intake from the reservoir consists of two intake towers made out of steel concrete. The second tower was executed at the same time with the partial change of the initial function of accumulation. Each intake tower has two galleries made out of steel concrete: the diameter of first water supply gallery is 800 mm, respectively 1,000 mm for the other one, used for emptying of the accumulation. The discharge of the flood waves is done through a spillway channel located on the left escarpment. The dam has works for the collecting of infiltration waters (124 self-discharge soil logs), located on the downstream slope and connected to a perimeter channel.

3. The Obtained Results

After an exploitation of 27 years, the dam shows a satisfactory functional status in what regards the structural integrity, its hydraulic response and its mechanical stability. After the year 1989, the functions of the hydrotechnical system were modified. At present, the achieved functions are: reducing the flood waves on the Crasna River, water supply for two towns, fish farming, and tourist area. Changing the initial function has determined, consequently, the designing and execution of several modifications in the dam's structure, as well as in that of the intake tower and the construction of a supplementary intake tower.

The new conditions of exploitation have determined the maintaining of a higher retention level and the intense usage of the hydro-mechanical devices within the intake tower. At the same time, the hydrotechnical system has repeatedly undergone actions of an endogenous nature. These actions have led to a diminishing state of safety in operating the hydrotechnical system, especially of the earthen dam and of the intake tower. The modification of the functioning conditions and the absence of corresponding constructions specific to earthen dams are still undergoing, determining a decline in the safety of the exploitation.

Over the years, while operating the accumulation, some important deficiencies have been noted, as result of incomplete implementation of the execution project, of the interaction between the construction and the incorporating elements, of the action of the endogenous and exogenous factors, a.s.o. Theoretical and experimental studies have emphasized the following observations (Expertiza tehnică…, 1997):

a) In the actual technical status, the dam cannot be included in the importance category specific to the previously named functions.

b) The dam presents a less slender cross section than in the project's design.

c) The upstream face of the dam is protected by a layer of riprap instead of concrete slabs. As a result there is an active process of infiltration through the dam with significant water loss from the storage basin. The infiltration current initiates and intensifies the internal erosion phenomenon.

d) The absence of waterproofing works of the dam has affected its stability, situation which has claimed imperatively a decline of the normal operating level of the lake.

e) The drop-down curve reaches to the downstream face of the dam at relatively high elevations affecting the slope stability of the dam.

f) The internal erosion phenomenon and its effects in time have determined modification of the structure of the material within the dam's body.

g) Due to the internal erosion phenomena, the emptying gallery at the old intake tower has an unequal subsidence up to 55 cm in its central area.

h) For normal pool level (NPL), boiling areas with ascending springs at the bottom of the collecting channel have been observed, without dislodging of solid sediment.

i) The physical and chemical analysis of the water evacuated by piezometer tubes indicates the presence of clay, due to the internal erosion phenomenon. The reddish coloring of the evacuation channel of the infiltration waters confirms the existence of this phenomenon. The absence of fine material in some piezometer tubes indicates that the internal erosion phenomenon is not permanent active.

Field test have emphasized a relatively non-uniform stratification in the studied section of the dam. This stratification is made up two geological types:

waterproof soils at the surface (dusty clay and argillaceous dust) covering cohesionless soils. The level of the underground water has been observed at depths of 1.60,…,4.80 m. This level is mostly located in the area of the waterproof formation at the surface. This shows the presence of pressurized water located in the cohesionless deposits beneath the waterproof layer.

For the calculation of seepage, we have conceived a computer program, compiled in Turbo Pascal, which can be used both for homogeneous and for non-homogeneous dams (virtual method), with or without downstream water, for the drained or undrained dams. The analysis of the infiltration process was carried out for the present day functional situations, as well as for the hypothesis of the rehabilitation and modernization of the dam. The verification was carried out in five different significant characteristic sections. New safety parameters for the dam corresponding modernization solution have resulted. The analyzed versions were (Expertiza tehnică…, 1997):

Version 1 – earthen dam with a drainage system, maximum level (p = 1%, exceedance probability) with the subversion: A – functional drainage of the downstream face of the earthen dam; B – blocked drainage of the downstream face of the earthen dam.

Version 2 – earthen dam with a drainage system, maximum verification level (p = 0.1%) with the sub-versions: A – functional drainage of the downstream face of the earthen dam; B – blocked drainage of the downstream face of the earthen dam.

Version 3 – earthen dam with a central concrete/steel concrete diaphragm (the new design version), with maximum level and maximum verification level.

Version 4 – earthen dam with a steel concrete screen (the design version).

The verification of the parameters of the infiltration phenomenon indicates a high diversity of values due to the heterogeneous composition of the filling materials and to the considered calculus hypothesis. Even in the case of a functional drain, there emerge situation in which the depression curve is in the close neighborhood of first berm and of the surface of downstream face of the dam, due to the characteristics of the material and the slender shape of the dam.

The analysis shows that the maximum level of infiltration through the dam is traced in calculus section 3 (near the first/initial intake tower. The parameters of the material are: k_{med} = 1.16 cm/s, ρ = 1,915,…,2,031 daN/m^3, φ = 8°15',…,15°35', C_{med} = 0.44,…,0.58 daN/cm^2). For the storage basin level with the exceedance probability calculus probability = 1%, the maximum specific seepage flow is q_{max} = 15 × 10^{-8} m^3/sm, with the spring of trickling on downstream face of the dam at a_0 = 3.82 m (Fig. 2).

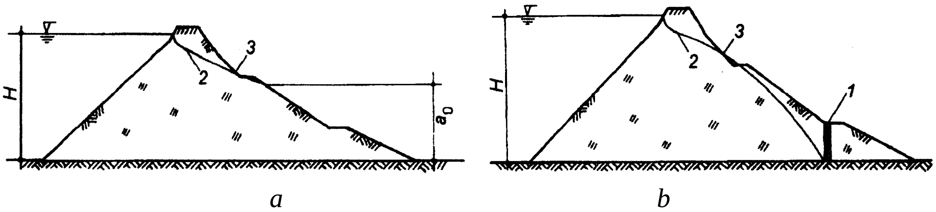

Fig. 2 – The position of the seepage curve at the maximum level hypothesis (p = 1%): *a* – blocked drainage; *b* – functional drainage; *1* – drain; *2* – seepage curve; *3* – spring point.

For the level with the exceedance probability = 0.1%, calculus section 3 becomes the most strained; here the elevation point of trickling on downstream face of the dam a_0 = 6.03 m has the highest value and the depression curve intersects first berm. In the hypothesis of the blocked drainage, the maximum specific infiltrated debit results in cross section **2**, having the value of q_{max} = = 24 × 10^{-8} m^3/s. This means that a possible try to over increase of the operating level of the lake can trigger the loss of the dam's stability, due to the appearance of the springing phenomenon on the downstream slope at very high elevations (higher that 6.0 m).

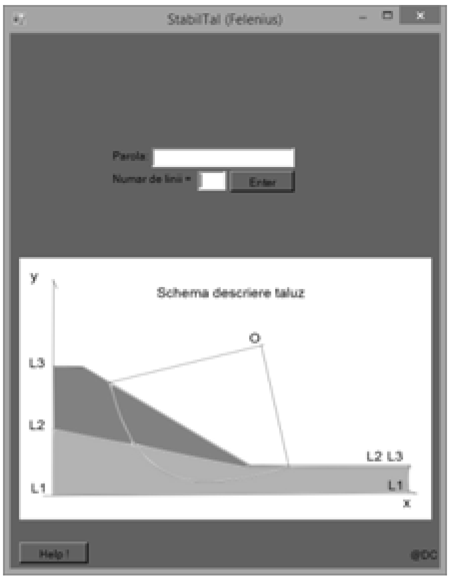

Fig. 3 – Screenshot of the self conceived stability program.

The stability calculus, carried out for several hypothesis also using a self conceived a computer program written in Tubo Basic (Fig. 3.), has emphasized relatively small and critical values for the stability coefficient (values of 1.121,…,1.129). The minimum value of 1.121, in the hypothesis of the blocked drain, indicated the risk of losing the stability of the downstream slope of the dam when the level of water in storage basin increases. In the drain functions, accordingly it results an increase of the coefficient up to the value of 1.151 (Expertiza tehnică…, 1997).

The analysis of the potential mechanical behavior/response of the dam was carried out with the method of finite element. The analysis was carried out for the plain status of deformation, a three dimensional model, and using on the market programs. The analysis was done for the interaction of the dam with the foundation terrain and in various hypothesis of action of groups of forces. The analysis of the tensions and deformation status was correlated with the physical and mechanical properties of the material worked with, based on the principles of the plastic theory applied to the local material (Crețu, 1980).

4. Means of Increasing the Safety in Exploitation Earthen Dams

In the case of Varsolt dam, the special risk situations are induced by the cumulative action of internal and external factors. These have determined functional situations with negative consequences in the case of maintaining the normal retention level. Such a situation is represented by the phenomenon of infiltration through the dam, which places the depression curve at higher values compared to the normal situation and calls for the decrease of the normal retention level by more than 1.0 m.
In order to avoid the risk factors and to increase safety of the dam following rehabilitation measures to have been recommended:

1. A complete implementation of the execution project by constructing the wall out of steel slabs on the upstream face of the dam. Modern solution will be utilized so that the functioning of the storage basin will not be disturbed.

2. The execution of the initial transversal section of the dam through embankment and molding the present shape. The upstream face of the dam as well as the downstream face must stick to the slopes shown in the execution project (1:2.0-1:3.50).

3. Decreasing the depression curve and ensuring the stability of the dam, by executing a drain beneath the downstream face of the dam.

4. Remodeling the system for collecting the water infiltrated through the dam's body and their evacuation.

5. Conclusions

1. A partial or total modification of the initial functions of hydro-technical system induces a series of new actions that can affect the safety in exploitation of the system by inducing supplementary risk factors.

2. The analysis of the safety in exploitation of the system is carried out through a hydraulical and structural type technical expertise which shows the systems behavior under new influences. In the studies case, the supplementary safety measures are also emphasized as well as measures for the technical rehabilitation and modernization of the hydrotechnical system.

3. In the case of the Varsolt dam, modifying the initial function, correlated with the absence of any waterproofing works undergone, led to the decrease in the normal retention level in order to avoid risking the dam's stability and loosing water from the storage basin.

4. Theoretical and field analysis has indicated critical values for the dam's stability parameters in the absence of complementary works regarding waterproofing and modernizing of the dam.

5. The special heterogeneous structure of the filling within the dam's body negatively influences its response to the infiltration waters, determining in some places mechanical erosion processes and scouring, even in the construction area and that of the incorporated equipment.

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VERIFICAREA SIGURANȚEI ÎN FUNCȚIONARE A UNOR BARAJE DE PĂMÂNT, FOLOSIND PROPRIILE PROGRAME DE CALCULATOR

(Rezumat)

Sistemele hidrotehnice îşi pot modifica în timp unele funcții pentru care au fost proiectate şi executate. Siguranța în exploatare a barajului şi a construcțiilor hidrotehnice anexe se analizează printr-o expertiză tehnică de tip hidraulic şi structural. În acest caz sistemul hidrotehnic este supus unor solicitări noi, care inițial nu au fost prevăzute prin proiectare. Sa studiat un astfel de caz, folosind propriile noastre programe concepute pentru a verifica situația actuală a infiltrațiilor prin baraj şi verificarea stabilității pantelor. Rezultatele obținute au relevat noii parametrii de siguranță ai barajului şi a dus la noi soluții pentru a controla fenomenele de eroziune hidraulică.