Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering. Vol. V, 2016
Print ISSN 2285-6064, CD-ROM ISSN 2285-6072, Online ISSN 2393-5138, ISSN-L 2285-6064

EARTH DAM STABILITY - THE ANALYSIS OF FILTRATION PROCESS

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Abstract

This paper presents research carried out on the earth dam stability to the combined actions of the site. The earth dam is located in Iasi, Romania. Researches were performed for several earth dam operating scenarios. First stage research considered the phenomenon of filtration through dam by Darcy's Law. Second stage of the research considered the filtration phenomenon according to post-Darcy law. Scenarios for monitoring the dam stability considered the main operating situations. The filtration and embankment behavior simulation was analyzed using a specialized soft. The studies and research results shows the differentiated behavior of dam slopes. The research results are used to design of dam rehabilitation works. Monitoring plays an essential role in evaluating the structural safety condition of dams. Monitoring activities are also useful for the collection of valuable data to enhance the understanding of the behavior of these structures.

Key words*: earth dam, Darcy filtration, post-Darcy filtration, slope stability.*

INTRODUCTION

Earth dams must be supervised at regular periods of time to analyze their operational safety. A series of values of dam structural parameters may change over time from those designed and executed.
The operational safety of the dam is affected if some parameters change. Structural parameters and functional status is verified by performing a technical expertise (Priscu R., 1976).
An important issue in earth dam evolution is uncontrolled seepage.
This directly influences the stability of structural components of the dam. The parameters of filtration phenomenon are changing over time depending on changes occurring geotechnical dam structure.
Fine material in the dam body is washed and the concentrated high speed flow through preferential paths appears. In this case there are no longer fulfilling the initial calculation assumptions (Darcy flow range).
Checking filtration phenomenon must consider the status parameters of the dam at the time of analysis. In the study should be reassessed geotechnical parameters, hydraulic parameters, hydrologic parameters, the new accumulation function etc. (Stematiu D., 1998).
The current dam operational situation requires the recalculation of the design flow and the verification of water level with various computation probability (p%) imposed by the new accumulation function.
The safe operation of the dam for the current operational status requires the development of theoretical and experimental studies. Hydraulic study carried out for the current and future state will evolve phenomenon of filtration. Analysis was carried out for various operating scenarios. The second study analyzed the stability of the dam on changed operating conditions. Results of the studies determine the measures to be taken to bring to normal the phenomenon of filtration. (Marchidanu, E., 1996).
Research conclusions determine the need of technical rehabilitation works of structural and functional components of the earth dam.
The Chirita Hydrotechnical complex is composed by an earth dam, a storage reservoir and a complex of hydraulic equipment. The Hydrotechnical complex is located in the south-east of Iași. Chirita reservoir is integrated in the water supply system of Iași city. The main purpose of the scheme design is storing and decanting water pumped from the Prut River.
The reservoir is on Chirita brook (Valea Lunga) and partially on Sapte Oameni brook.

Valea Lunga brook is last but one tributary on the left Bahlui River before its confluence with the Jijia river. The Valea Lunga land code is XII – 1.15.32.23.

The hydrographical basin characteristics are: reception area of 37 km^2 (44 km^2 total area); brook length from the source to the Valley Chirita 13.1 km (16 km total length); average slope from the source to the Valley Chirita: 7.67‰.

Chirita reservoir was designed and constructed in 1962. Chirita dam is made of earth taken from the left side of the reservoir. The main execution material was compacted loess clay.

The dam has a trapezoidal cross section with berm on downstream and upstream faces. The dam crest length is 219.00 m; the crest width is of 6.00 m. The upstream face is protected by a concrete slab riprap (1.0 x 1.0 x 0.15 m). The upstream riprap face protection is realized where is the water level variation zone.

The dam presents a filter blanket of broken stones. On 3/4 of the width, the dam is equipped with a drainage blanket of fine sand, sandy gravel + grit + gravel as a reverse filter.

At the downstream end of the mattress it was performed a gravel filter prism covering drain. The drain has a diameter of 300 mm and is made of reinforced concrete pipes. The drain collects and discharges the water filtrated through dam body.

Along the drain length are made three connections and branch manholes. At central manhole is plugged a concrete pipe (D = 300 mm) for evacuation of infiltrated water into a conduit. The conduit is connected to the Chirita brook. [Luca, M., 2002]

The characteristic level and geometrical parameters of earth dam are: 42.40 maBSL ground level; crest level 54.60 maBSL; concrete slabs level = 53.00 maBSL; upstream slope of 1:3.5 and downstream slope of 1:2.5; upstream berm level 49.60 maBSL; downstream berm level 49.00 maBSL; crest width 6.00 m; crest length = 219.00 m.

Flow rates from Table 1 characterize Chirita brook. Reservoir capacity was designed to store a volume of water pumped from the river Prut. Chirita reservoir is a pre-decantation lake for the water supply system of Iasi city from the River Prut.

a

b

Figure 1. Overview of the dam Chirita: a - upstream; b - the downstream.

Table 1. Characteristic flow values with computation probability p (%)

p, (%)	50	10	1.0	0.1	0.01
Q_p, (m^3/s)	0.50	31.0	90.0	175	270

Table 2. Characteristic dam levels for flows with calculation probability p (%)

p, (%)	minimum	medium	maximum	1.0	0.1
N_p, (maBSL)	50.0	51.0	52.0	52.40	53.76

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Figure 2. Overview of the earth dam and the spillway

In the dam site area are present lithological stratifications of loess clay dust composed, silty sand mixed with gravel, silty clay and marl clays (especially in foundation). Mostly, these deposit supplied materials for the dam execution. The dam of Chirita reservoir is made of local materials taken from the left side of the lake. The main execution material is compacted loess clay.

STABILITY PARAMETERS ANALYSIS FOR EARTH DAM

In the analysis of the stability of embankment dams are taken into account several assumptions. The analysis takes into account the following:
-The structural dam type (shape, slopes, number of berms, cross section and plan dimensions);
-Geo-mechanical characteristics of the materials used in execution;
-The collection and disposal methods of filtrated water;
-Exploitation conditions (water level variance upstream and downstream);
-Assumptions analysis that reflect the operational process etc.
Slope stability analysis on an earth dam is made with two assumptions:
-Hypothesis - slope design with known mechanic-physical parameters of the soil (γ, Φ c) and main functional criteria imposed by the geometrical characteristics (height, depth, width canopy).
The calculation results indicate the slope value in stable conditions;
- Hypothesis - verify the executed slope stability with well defined geometry, to estimate the stability reserve (Ratiu M., 1989).

Table 3. Safety coefficients

Actions	construction status	The working hypothesis	Check slope	$Fs_{admisible}$	
				no seism	with seism
fundamental	A the end of construction	-	upstream downstream	1.30	1.30
accidental	The current exploitation	lake full to the retention maximum level	downstream	1.50	1.20
		lake partially filled	upstream	1.50	1.20
	Sudden draining	At normal retention level	upstream	1.30	not verified
		At maximum retention level	upstream	1.20	not verified

The slope stability is estimated in both analyzing hypothesis (design, verification) comparing two safety coefficients ($Fs_{effectiv}$), and restriction coefficient ($Fs_{admisible}$). The analysis equation is:

$$Fs_{effectiv} < Fs_{admissible}$$

Evaluation of stability coefficient is achieved in several assumptions:
- Construction period;
- Exploitation period (full reservoir);
- Sudden draining of reservoir.

The literature presents the safety coefficients for the construction verification for various groups of actions and conditions of the verification (Table 3).
Earth dam stability is influenced by two characteristic phenomena: the slopes sliding and the filtrate water through the dam. The two phenomena are coupled in the analysis model.
Researches were performed for various operating scenarios of earth dam. Phase I research considered the phenomenon of filtration through the dam in the area of validity of Darcy's law.

Phase II of the research considered the phenomenon of post-filtration according to Darcy law.

Study situation is imposed dams showing suffusion phenomena, sinkhole, subsidence, etc. Laws in the Post- Darcy filtration believe in a differentiated intervention force of inertia (Luca, Al., L., 2014).

Stability analysis of earth dam is done by using specialized software. The most used are: Galena, Chasm, SecuSlope, Robot-Milenium, Breach etc.

RESULTS REGARDING THE CHIRITA DAM STABILITY (FIRST STAGE)

Chirita dam stability was analyzed using Galena program. The program is applicable to earth dams. Through the program can be calculate the slope stability under various scenarios of exploitation of the reservoir.

The input data required by the program are those that define the slope geometry (Figure 3), geotechnical properties of the earth, dam filtration characteristics, forces that are applied for and appear on dam including seismic force (Figure 5).

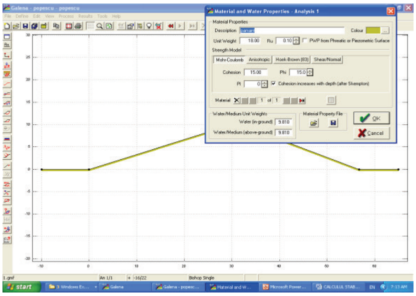

Figure 3. Defining the embankment parameters

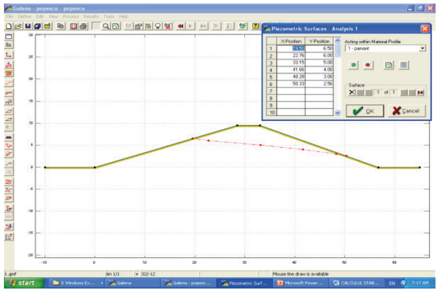

Figure 4. Defining the seepage curve

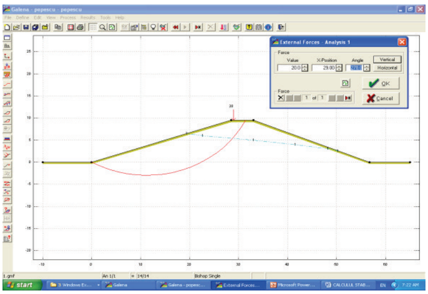

Figure 5. Defining loads

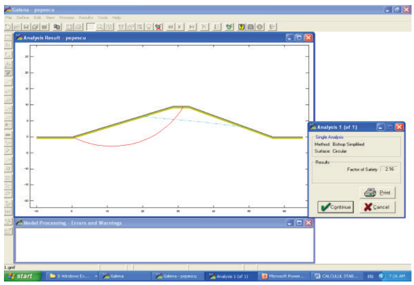

Figure 6. Display safety coefficient

The program uses three methods to analyze slope stability: Bishop, Sarma or Spencer Wright. Specifying center of the embankments critical failure circle is achieved by using Janbu nomograms (P Cercel, 2011). Janbu nomograms specify explicitly the position of subsidence circle center by geometric and geotechnical parameters of the slope. The output is the value of $Fs_{effectiv}$ stability coefficients (Figure 6).

The program allows the introduction of concentrated load or evenly distributed hydrostatic pressure, and seepage curve (Figure 4), different layers of earth or different surface discontinuities.

The plan model of analysis considers the earth dam cooperation (loess clay and silty clay) with foundation soil (sand dusty gravel and clay marl) in various risk situations (hypotheses/analysis scenarios).

Analysis scenarios were:

-Blocked spillway given by bridge collapse.

-Blocked spillway by floating objects during flood.

-Accidentally hypothesis of reaching the maximum level of retention.

The analysis shows the effect of body weight dam considering the embankment in both dry and saturated conditions, the hydrostatic pressure, the ice pressure, the wave action, the seismic response of the earth dam at maximum credible site seismic action (0.2 g peak acceleration) (Cretu I., 1980).

According to the lithological profile through the valley and performed geotechnical study of the implementation of the dam, the materials are clay loess and clay dust.

The materials used in the model for computation for "dry material" are:

A. Dry compacted clay loess. Geomechanical characteristics are: E_1 = 300 daN/cm^2, G_1 = 120 daN/cm^2, υ = 0.17 and γ_1 = 0.00184 daN/cm^3.

B. Silty clay layer (at the contact between dam body and the foundation). Geomechanical characteristics are: E_2 = 300 daN/cm^2, G_2 = 120 daN/cm^2 υ = 0.17 and γ_2 = 0.00184 daN/cm^3.

C. Dusty sand with gravel (foundation soil). Geomechanical characteristics are: E_3 = 200 daN/cm^2, G_3 = 80 daN/cm^2 υ = 0.17 and γ_3 = 0.0019 daN/cm^3.

D. Marl clay (bedrock). Geomechanical characteristics are: E_4 = 316 daN/cm^2, G_4 = 125 daN/cm$_2$, υ = 0.17 and γ_4 = 0.00184 daN/cm^3.

E. Clay dust (old dike). Geomechanical characteristics are: c = 0,18daN/cm^2, φ = 15 °, γ = 16.70 kN/m^3 and cohesion was considered increasing with depth.

The loading types/actions and their coefficients considered in the calculation model are: permanent loads, long term temporary loads, short-term temporary loads and exceptional loads, according to the norms for calculation of hydraulic structures (Luca M, 2009).

Infiltration line calculation was realized using Numerov method (Pietraru V., 1987).

Free water surface is calculated using Numerov formula:

$$x = \frac{H^2 - y^2}{2 \cdot \frac{q}{k}} - H \cdot F_1 + \frac{q}{k} \cdot F_2$$

$$\frac{q}{k} = \frac{H^2}{L + H \cdot f_1 + \sqrt{(L + H \cdot f_1)^2 + H^2 \cdot f_2}}$$

where:

x and y are coordinates of the line of free water surface (y=0...H), H is water level used in calculations, F1 and F2 are functions with 2

two arguments m1 and $s = th\left(\pi\left(H - y\right) / \frac{2q}{k}\right)$

The reservoir water level has been considered being the normal operating level, 52.50 maBSL, corresponding to a water depth of 9.50 m in the master section.

Table 4. Parameters for setting the seepage line blocked draining blanket)

X(m)	0	11.98	18.83	24.77	29.79	33.90	37.10	39.11
Y(m)	9.5	8	7	6	5	4	3	2.14

Pavlovski method was used to study the seepage through earth dam with a downstream drainage blanket. If the drainage blanket stops working, being blocked the dam will behaviour like a homogenous dam on impervious foundation.

If the drainage blanket stops working the seepage line will undergo an average lift of 0.50 m compared with the situation when the drainage blanket works. Seepage line in the two main operating cases is shown in figure 7 and figure 8.

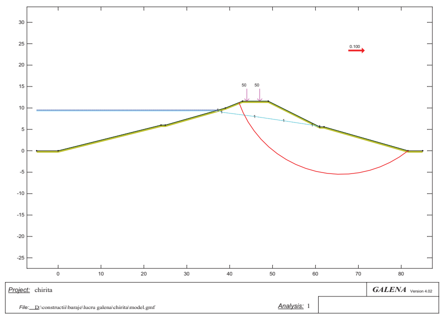

Figure 7. Seepage line when the drainage blanket is working

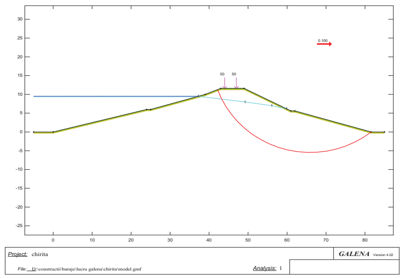

Figure 8. Seepage line when the drainage blanket is blocked

After running the analysis the results for stability coefficient computation (Phase I, where Darcy's law is valid) are presented in Table 5.

Verification of stability parameters of earth dam requires reconsideration of geometrical, geotechnical, seepage parameters etc. at the time of analysis (Carlier M., 1972). For this purpose, it must be carried out geotechnical and topographic surveys on studied objective. From initial design parameters and those existing at the moment of analysis there are differences that may affect the value of the results.

Table 5. Stability coefficient resulted

The hypothesis taken into account	downstream slope	upstream slope
Full lake	1.488	3.47
Lake suddenly drained	1.489	1.938
Empty lake	1.674	1.917

The resulted coefficients were determined taking into account the possibility of occurring an earthquake. It was verified the downstream slope stability on the assumption of full lake, the load is a truck on the dam and the presence of an earthquake (in both cases the calculation of the infiltration line).

Results show that stability coefficient values for downstream and upstream slopes are within the recommended values (the limit values for the operating conditions) for this type of dam. In this analysis was considered the worst hypothesis for the seepage curve position (partially clogged drain).

CONCLUSIONS

Earth dams must be supervised at specific periods of time for monitoring the structural safety especially the slope stability affected by combined action occurring.

Chirita earth dam has a good functional status in terms of functional structural integrity and slope stability, given the long life (about 48 years).

The dam doesn't present uneven settlements neither in cross section nor in longitudinal section, landslides or collapse on upstream or downstream slope, sinkholes or uncontrolled infiltration. Checking the slope stability of the earth dam requires considering the geometrical and geotechnical parameters and the seepage at the time of analysis.

Determination of seepage line parameters through dam have to consider the current state of the material of the earth massive after a long period of operation.

From data analysis, the results for Chirita dam show that it is met the upstream and downstream slope stability in the considered scenarios.

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