DOI: http://doi.org/10.21698/simi.2017.0010

NEW SOLUTION IN REHABILITATION OF THE HYDRO-POWER SYSTEMS NOW IN RISK DUE TO THE INFILTRATION

Victorita Radulescu

University Politehnica of Bucharest, Faculty of Energy, 313 Splaiul Independentei, Sector 6, Bucharest, Romania, *vradul4@gmail.com*

Abstract

In Romania, there are more than 200 dams realized during 1975-1990 from local materials, without any ulterior remediation or rehabilitations. Nowadays, many hydropower systems confront with infiltration through dams or lateral dikes, followed by unexpected erosions. In order to maintain the hydropower system active, the water level is drastically reduced, sometimes even with 10 m. Consequently, it means less water for the human necessities (water supply, irrigation), but mainly few resources to produce electric energy. The research paper starts by presenting the actual dams situation, structured on hydrographic basins. For the case study two hydropower lakes from Arges-Vedea hydrographic area that confront seepage through embankments were selected. In that area there are more than 100 lakes which confront with different functioning problems. The local geomorphologic structure and the water quality create an image of local functioning conditions. Further, there are briefly presented the mathematical and numerical models, elaborated as to establish the infiltration risk zones. The numerical model is tested and calibrated based on local conditions, showing the zone with erosion and infiltration risks. Finally, some conclusions, possibilities to extend the numerical model, the acknowledgements, and references are presented.

Keywords: *energy efficiency, environmental engineering, hydroelectric power generation, mathematical model, numerical simulation*

Introduction

First, it must be mentioned that there are 636 dams constructed from local materials nationwide, which have a number of shortcomings (revealed by the analyzes carried out in the last four years), as follows: 134 dams have damaged tiles and the grout; 69 dams shows infiltration into the dams body and the downstream areas; 143 have erosions through dams at access roads and pears;186 dams have the bottom of the emptying zone blocked, with major defects in the water discharge area, or are not equipped with surge arresters surfaces; 21 dams have flaws and are not functional; 35 dams have the basin's reservoirs filled with sediments at a rate of over 50%; 63 dams are abandoned without legal documentation or regulatory acts; 5 dams are proposed to be listed in the case of abandonment as required by law of the results (Radulescu & Nistreanu 2004).

The most serious of the problems mentioned are the infiltration into the dams body and the downstream areas, the erosions through dams at access roads, breaches in dams and lakes clogging (the lakes that are part of the case study have clogging of over than 50%). It should be mentioned that from the 640 dams, about 270, meaning almost 40%, have major problems. All these issues have diminished the payload, and

limited the possibilities to produce electricity. This happens at the same time with the worldwide efforts to develop new possibilities for intensive uses of renewable electricity generation, in the context of carbon dioxide emission reducing. A report on the dams' flaws is presented in Table 1.
The Arges-Vedea hydrographic basin is located in the south part of the country and has an area of 20.911 km^2 including the basins: Arges-12.590 km^2, Vedea-5.430 km^2, and Calmatui 1.413 km^2, out of the basin side of the Danube-2.025 km^2.

Table 1. Actual Situation of the Dams with problems in Romania

HB	ND	DT	I	SLP	PD	DD	CL	A	D
Someş – Tisa	33	21	5	3	3	0	1	0	0
Crisuri	31	6	4	9	22	0	0	0	0
Mures	10	6	0	1	1	1	1	0	0
Banat	1	0	0	0	0	0	1	0	0
Jiu - Dunăre	4	0	0	1	1	0	2	0	0
Olt	45	19	6	8	11	0	1	1	0
Arges – Vedea	119	24	18	43	29	0	0	1	4
Buzau-Ialomita	28	0	0	3	17	0	0	7	1
Siret	76	15	17	2	23	0	9	19	0
Prut - Barlad	285	43	19	71	79	20	18	35	0
Dobrogea – Seaside	4	0	0	2	0	0	2	0	0
TOTAL	636	134	69	143	186	21	35	63	5

HB - Hydrographic Basins, ND - Number of Dams, DT - Damaged Tiles, I - Infiltration, ESP - Erosions Slopes, Pears, PD - Problem Discharging, DD - damaged dams, CL - Clogged Lakes, A - abandoned, D - Decommissioning

The network has an average density of 0.36 km/km^2 ranging from 0.67 km/km^2 on the high mountains zone, 0.507 km/km^2 in the middle and up to 0.03 km/km^2 in the lower altitudes. Previous research results showed that the specific annual average leak in the mountains reaches 30-35 m/s/km^2. The value is due to the rainfall from the collecting basin, with an annual average of 1400 mm, and to the drain of the petrographic substrate with sharp slopes, and a good waterproofing of slopes. The lowest leakage is in the plain area, of 3 l/s/km^2, where rainfall values are much lower, with an annual average of 600 mm. The drain slopes are less pronounced and the petrographic substrate is permeable. The catchments area Arges-Vedea includes the following counties: Arges, Dambovita, Olt, Teleorman, Giurgiu, Calarasi, Ilfov and Bucharest territory.

Materials and Methods

In order to calibrate the numerical model, it is necessary to collect samples referring at hydrologic capacities, average values of rainfall, type of nature and dimensions of sediments, favorable area for infiltrations through dikes and dams (Bockman & Tom 2008). It is necessary to compare the obtained results with existent measurements database. Further, some measurements considered significant for further environmental analysis are mentioned.
In these conditions the main analyzed microclimate characteristics are:
- average annual temperature 8.5°C, medium temperature of January - 4.5 °C; average temperature of July 20°C;
- relative humidity 80 %;

- average rainfall during a year 500-600 mm (450 mm during summer);
- wind average velocity during the entire year 3.6 m/s, at the level of 10 m high.

Significant rainfalls variations appear in July-November; the quantities being even greater in the higher zones.

In Arges-Vedea hydrographic basin there are 24 hydropower lakes, from which 16 are in the Arges basin. The hydropower cascade lakes on Arges river, downstream the CHE Vidraru, are generally equipped with Kaplan turbines, with hydraulic falls between 10-20 m and electric power range between 8-16 MW, depending on the energy sector. There are hydropower plants (HPP) with dams at distance (Oiesti, and Cerbureni), with hydropower plants near the dams (Curtea de Arges, Zigoneni, Valcele, Budeasa, Bascov, Pitesti, and Mihailesti) or bypass-type hydropower plants (Albesti-Iasi, Noaptes, Baiculesti, Manicesti and Merisani).

The development scheme of the Dambovita river is generally for electricity production at Clabucet (P=64 MW), Rucar (P=23 MW), Dragoslavele (P=7.7 MW), Frasin P=0.6 MW), and Vacaresti (P=4.84 MW) and meets the needs for water suply of Bucharest and irrigation basins Dambovita and Colentina. The River Targului, where there are some HPP with significant problems, was developed to assure the water supply for Campulung city and electricity production in Leresti (19 MW), Voinesti (5.2 MW) and Schitu - Clears (1.55 MW).

Ialomita River is one of the oldest electric hydropower systems in Romania. There are three hydropower plants: Dobresti P=16 MW, Moroieni P=15 MW, and Scropoasa P=12 MW. Two lakes were selected for this analysis, confronted with massive infiltrations through dikes and dams, one on River Targului and one on Capra River. For this areas, 8 periods of significant increases in level and flow have been identified, most notably in April, July, and December. In these times, nationwide, of 32 stations danger levels were exceeded: in 10 - Danger of flooding, level was, in 14- flooding level and in 8 - damage level (Table 2). The most affected basins were in the southern half of Vedea, Cotmeana, Teleorman, Dambovnic, Neajlov, Urlui, and Calmatui. Regarding the maximum leakage at the two stations, they have exceeded the historical flows. The annual precipitation values recorded for the entire hydrographic basin were between 686.5 - 1304.5 l/m^2.

Table 2. Values registered for the flow rate in different stations

Nr.	Hydro Station	River	AMA (m^3/s)	AD (m^3/s)	%
1.	Ciobani	Cotmeana	0.866	7.32	845
2.	Buzesti	Vedea	0.969	11.0	1135
3.	Valeni	Vedea	3.16	28.5	902
4.	Tatarasti	Teleorman	1.06	11.6	1094
5.	Mill Groapa	Neajlov	1.07	15.3	1430
6.	Slobozia	Dambovnic	1.17	12	1026
7.	Balilesti	Bratia	2.73	6.73	247
8.	Rausor	Rausor	0.733	1.63	222
9.	Priboieni	Carcinov	0.589	1.92	326
10.	Gura Foii	Potop	0.578	3.64	630

AMA - Average Multi-Annual flow rate, AD - Average December

The infiltration through dikes and dams represents in many cases a major problem. Solving the stability problem for dikes and embankments is the main purpose of the present analysis. Schematically, the problem of seepage through dams can be presented, as in Fig. 1-a, and in reality it can be seen in Fig. 1-b the appeared infiltrations.

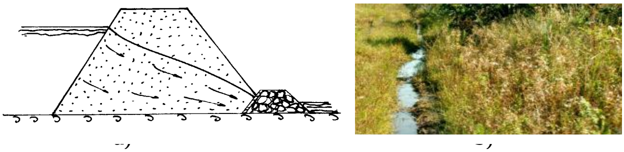
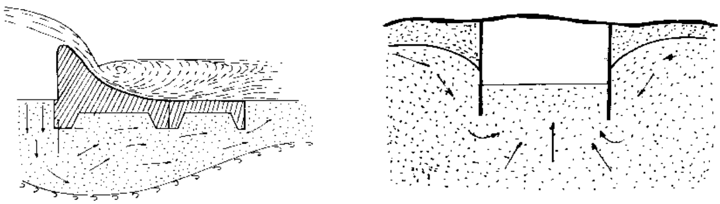


Figure 1. Schematic and real infiltrations through dikes and dams

In Fig. 2-a, the dam is realized from local materials, with a drainage prism at the bottom of the downstream face. Size selection for such a dam can be based only on a study of the seepage through the dam. In Fig. 2-b a dam realized of concrete is represented, founded on a non-cohesive land.



a) b)

Figure 2. Different solutions of dam executions

Here (in the second case), due to the water infiltration under the concrete constructions, it is particularly important to estimate the pressure exerted on the construction by the groundwater. It is necessary to determine by mathematical models the water velocity which goes out, the underground downstream after the concrete slab. A problem is represented by the evaluation of infiltration speed; dω is an elementary cross-section of the elementary seepage, and dQ the infiltration flow through this elementary area. In this case, the infiltration rate is (Seteanu & Radulescu 1998):

$$U = \frac{dQ}{d\omega} \tag{1}$$

The infiltration rate is different from the actual velocity at which the water flows through the earth pores. If ω is the total area of the filter, ω' is the surface of all the pores, then the actual average speed through the soil pores, V' will be:

$$\mathrm{V}' = \frac{\mathrm{Q}}{\omega'} \tag{2}$$

Noting with $p = \dfrac{\omega'}{\omega}$ the porosity coefficient, the velocity becomes, $V = p \cdot V'$.

The flow rate is:

$$Q = k \cdot \omega \frac{h_w}{J} \tag{3}$$

where: k-is the infiltration coefficient, ω-the cross-section area, h_w-the hydraulic losses between sections 1 and 2, situated at distance l, H_1 and H_2 the static loads in specified sections, and the hydraulic slope $J = h_w/l$ (Vagma & Torn 2006).

$$h_w = H_1 - H_2 \tag{4}$$

With these notations, the infiltration velocity may be written (Aqeel, Al-A 2013):

$$U = -k \cdot \frac{dH}{ds} \tag{5}$$

One of the following methods may be used to evaluate the infiltration coefficient:
- Relations with computing, which includes physical soil constants
- Experimental laboratory measurements on soil samples
- 'in situ' measurements by sample pumping or injection

Hazen relation has been used in the numerical model:

$$k = A \cdot c \cdot \tau \cdot d_e^2 \tag{6}$$

where (Seteanu & Radulescu 2005):
- A - coefficient depending on the measurement system, A=1 if k is in m/day,
- c - coefficient depending on the sands clay content, so for the clean sands c = 1000-700, and for sands with clays c = 700-500; d_e(mm)
- the effective diameter defined by the diameter of the granule to which the soil samples are lower, only 10% (by weight) of the granules of the earth.
- τ is a correction factor depending on the temperature (t^0 in degrees Celsius)

$$\tau = 0{,}70 + 0{,}03 \cdot t^o$$

The Hazen relation may be applied to sand with d_e= 0.1-3 mm and soil non-homogeneity coefficient, that the ratio $d_0/de \leq 5$ (d_0 being the diameter of the pitch to which 60% of the granules have a smaller diameter).

Results and Discussion

The seepage through both the embankments (the right bank and the left one) have been modeled. For each case three water levels have been chosen in the lake. For modeling, the cross-sections quotas mentioned in Table 3 deemed special problems of the current exploitation were chosen. The downstream dike is discontinuous, consisting of fine sand, medium or rare gravel, sandy clay, loam sands, lens mud, and vegetal elements. The bedrock is alternate marl clay, marl, tuff, and fine sands, (Radulescu & Zetenyi 2009).

Table 3. Analyzed cross-sections

Dike left bank						Dike right bank			
Developing area	Manifestation					Developing area	Manifestation		
Profile	BU	BB	RU	TU	G	Profile	BU	BB	G
300.5- 300.6				X		410.0- 413.0	X	X	X
303.1-303.4			X	XX	X	416.7-417.0	X	X	X
303.8- 303.9			X	XX	X	429.0- 430.0	X	X	
303.0- 304.0				X		434.0- 435.5	X		
303.6- 304.5			X		X	437.5- 437.9	X	X	X
307.1- 307.3	X	X			X	438.5- 439.5	X	X	X
307.5- 307.9	X				X	439.0- 446.3	X	X	
308.0- 308.2	X					445.0- 445.9	X	X	X
356.0- 356.2	X	X				458.0- 460.0	X	X	
						462.0- 465.0	X	X	

BB - puddles on lateral side, BU - wet–lateral side, TU - wet batter, RU - wet ramp, G - ice on lateral side, X - appearance of the mentioned phenomena, XX - very intense mentioned phenomena (Seteanu & Radulescu 2004)

For these sections the flows in 24 cross sections for different levels in the lake were modeled. For each variant three sub-variants were tested:
Variant A1, B, and C1 - state of the shield would be built into the bedrock, and the upstream lateral side has a compact sealing mask, without cracks. It represents the ideal case. In this case, there are no leaks. Experience has shown that any screen is that is not embedded in the bedrock or the mask is not compact (there are cracks in the sealing portion, is broken, etc.).
Variant A2, B2, and C2 - with the shield case is embedded in the bedrock and the lateral side upstream has small cracks in the waterproofing mask.
Variant A3, B3, and C3 – the shield is not embedded in the bedrock, and the lateral upstream sides have cracks on relatively large portions, often the sealing being destroyed. This is the reported case, and the two sides (left and right) were molded separately, with the specific permeability, designated A-3A, A-3B, B-3A, B-3B, C-3A, C-3B. For the studied domain the mesh was performed for each cross-section, depending on the specific material permeability in the structure, Figure 3 - 5. Each field is represented by a different color. Depending on the material characteristic, the water level in the lake and the cross-sections, the depression curve is determined. The program performs automatic finite element meshing, based on which the calculation is performed. The streamlines are plotted, and the infiltration velocity is obtained. Further some results are presented for each of the cases mentioned above.
The seepage quantity through the dam and lateral dikes can be observed in the Variant 3, indifferent of the case. The velocity has a wide distribution, which quickly leads to erosion and destruction of the concrete slabs.

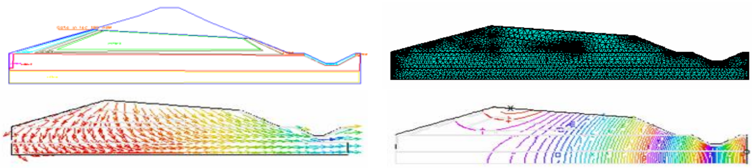


Figure 3. Results for Variant 1

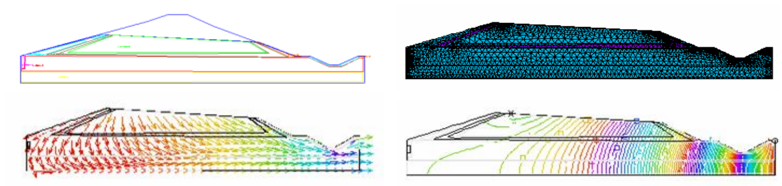


Figure 4. Results for Variant 2

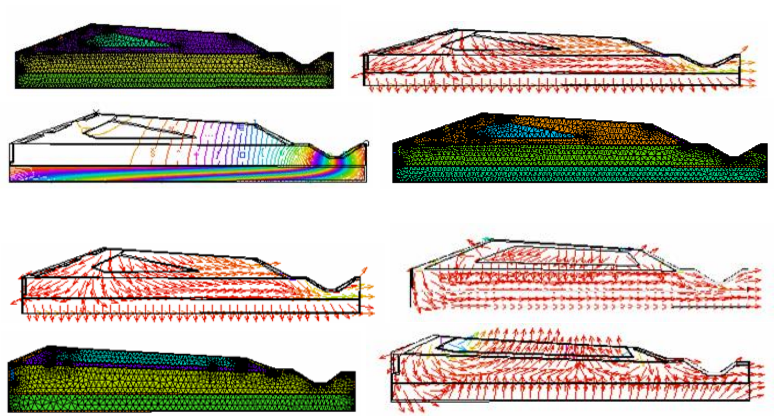


Figure 5. Results for Variant 3-Case 1, Case 2, Case 3

Conclusions

The nationwide situation of the hydroelectric plants confronted with various problems in operation was presented. For the testing area, hydrographic Arges-Vedea basin some data collected "in situ" was presented. It is necessary to calibrate the numerical model that was developed based on the presented mathematical model. The numerical model highlights areas of infiltration followed by a rising erosion risk.

By changing the cross-section structure and dam permeability, a complete risks modeling can be achieved of the any dam now in operation. This way, an image of the risk areas that need to be monitored continuously can be realized, as well as of the sections for which urgent maintenance and repairs should be done (Turbatu et al. 2004).

Acknowledgements

I would like to thank my colleagues from the "Romanian Waters" and from the Hidroelectrica SA, who presented to me the problems appeared into these hydrographic river basin catchments, and supported me in the realization of the numerical platform and have been physically realized the rehabilitations for the SHP mentioned.

References

Radulescu, V & Nistreanu, V 2004, *'Sisteme hidraulice de aductiune'*, Bren Publisher, Bucharest, ISBN 973-31-1412-X.

Seteanu, I & Radulescu, V 2004, *'Numerical models in hydraulics and power engineering',* Bren Publisher, Bucharest, ISBN 973-99604-4-8.

Seteanu, I, Radulescu V, & all 1998, 'Sisteme hidraulice, Fundamente si aplicatii, Editura Tehnica, Bucuresti ISBN 973-31-1412-X.

Aqeel, Al-A 2013, 'Study of infiltration and stability of the earth fill dams, Proposed Kashkan dam as a case study', *University of Kufa Journal*, vol. 4, no. 2, Iraq.

Bockman, T & Tom, H 2008, '*Investment timing and optimal capacity choise for small hydropower projects*', Energy, Elsevier.

Radulescu, V & Zetenyi, Z & all 2009, 'Utilization of renewable resources in rehabilitation of existent micro-hydro power plants*', Conference Hydro*, pp.156-163, Lyon, France.

Seteanu, I & Radulescu, V 2005, 'Identification, calibration of the hydraulic parameters-linear optimization*', Romanian Journal of Hydrology & Water Resources*, vol. 2, No. 1-2, pp.33-37, ISSN 1223-1126.

Turbatu, A, Radulescu, V & Abrudan, T 2004, *'Eficientizarea conducerii operative a centralelor hidroelectrice prin urmarirea on-line a parametrilor de functionare. Aplicatie la SH-Curtea de Arges', Revista Energetica*, An.49, nr.8-9, pp. 432-436, ISSN 1220-5133.

Vagma, I & Torn, H 2006, 'The impact of infiltration dam on the groundwater regime in the Kurtna landscape reserve area', *Journal of Oil Shale*, vol.23, no.1, Estonian Academy Publisher, ISSN 0208-189X.