ISSN 1453 – 7303 **“HIDRAULICA” (No. 3/2018)**
Magazine *of Hydraulics, Pneumatics, Tribology, Ecology, Sensorics, Mechatronics*

A Method to Address the Fixing of Sealing Deficiencies at the “Ostrovul Mic” Left Bank, “Râul Mare - Downstream” Water Development

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Abstract: *The present paper proposes a method for approaching the remediation of sealing deficiencies from the left bank of Ostrovul Mic water reservoir at km1+300 (Raul Mare – Downstream water development) by executing a drain at the bottom of the side embankment downstream face. The results of the remedy are highlighted by checking the flow both as a permanent regime and as transitional regime hypothesis on a 2D numerical model.*

Keywords: *Embankment, sealing, water infiltration, interception drain, 2D numerical modelling.*

1. General considerations

The hydro-power arrangement Ostrovul Mic (figure 1) is located at a distance of about 20 km from the Town of Haţeg, in the surrounding area of Ostrovul Mic village. The specific water development consists from a low retaining concrete dam, a hydro-power station and side enclosing embankments. The main uses of the arrangement are the electric power production, the water flow adjustment on river Râul Mare and the farm land irrigations. The concrete overflow dam accomplished towards the right bank is of “storied” type, with a tympan (H = 22,50 m), an over-spilling hood and a bottom discharger endowed with 4 tainter gates (4,00x4,00m^2) and 2 flap gates (10,00x2,50m^2). The usual water retention level is set at 465,00 mSL. The power station Ostrovul Mic is situated on the retention section towards the left side and is endowed with two Kaplan turbines. The installed flow of 90 m^3/s and its nominal head of 20 m leads to an installed power of 15.90 MW [1].

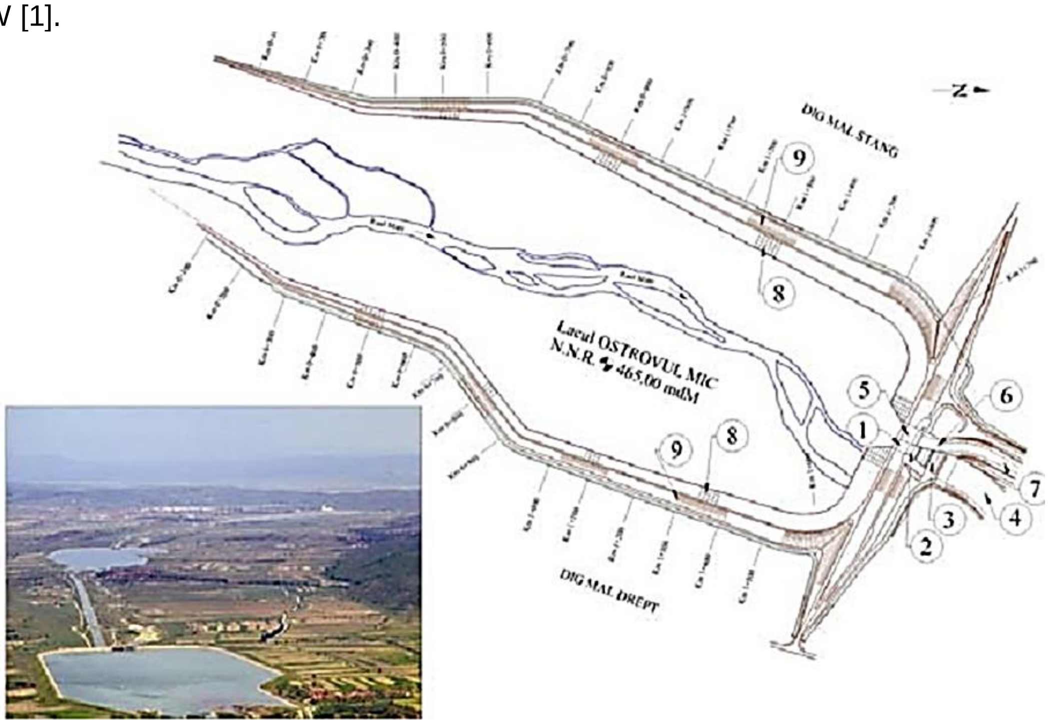


Fig. 1. Plan view and panoramic photo of the Ostrovul Mic water development. 1. overflow dam, 2-3. first and second steps of the energy dissipater, 4. high waters canal, 5. hydro-power station, 6. apron basin, 7. tale-race canal, 8. reinforced concrete face, 9. grassy downstream face.

Due to significant exfiltration accompanied by material entrainment from the enclosing embankments (especially at the left bank dike) the water development runs on level restrictions, meaning substantial energy and consequently financial losses. The enclosing ballast embankments of trapezoidal cross section have a 4.00m wide crest and faces slopes of 1:2.0 and 1:1.8 (upstream / downstream). The filling material – ballast – was obtained from the reservoir basin. The sealing is accomplished by an upstream reinforced concrete face (slabs 4.00x5.00m^2) of 0.15-0.20 m thickness and an underground slurry (bentonite) wall. The concrete face is upper ended by a water wave concrete turning parapet of 0.50 m height. The slabs joint gaps were sealed with bituminous mastic while the expansion joints are additionally sealed with glued straps.
The base ground layer – marl – is to be found at a depth of about 8…10 m from the natural ground level and therefore the underground sealing groin was difficult to be properly done by the following technological solution: the concrete face was to be deepened with about 4 m under the ground level, the remained depth was trench opened by excavation down to the base layer and filled with bentonite, a reinforced concrete supporting beam was accomplished on top of the slurry groin. Unfortunately, engaging this accomplishment procedure led to at least two types of inconveniences: there are zones where the trench excavation did not reach the marl layer, as it clearly proves to be the case on the left bank embankment at km1+276 where there is a bentonite uncovered gap of about 1…2m depth under the slurry groin (an exfiltration funnel developed here along the first 10 years of running the water arrangement, nourishing multiple springs on the downstream face and in the alongside safety counter duct); there are zones where it seems that the supporting beam does not properly vertically overlays with the slurry filled trench. It also needs to be mentioned the advantage offered by the embankment ballast fill granulometry which creates a solid skeleton hardly to be destabilised by exfiltration.
Along the 1996…1999 time period of running several exfiltration zones appeared and developed on the left side embankment downstream face (berm level) and its alongside duct, specifically at km0+790, km1+300 and km1+670, reaching an exfiltration discharge of 196 l/s. Geotechnical studies were then performed by digging three wells right down to the marl base layer (441,5 mSL) [2, 3]. Following the heavy rains of 12-14 July 1999, developing in torrents of extraordinary flow level, the water turbidity in the reservoirs maintained itself at very high values (as yellowish brownie viscous fluid) for about two months and it was noticed that the exfiltration at km1+300 seized for 8 days in order to reaper in the beginning at a half of its prior rate. The reservoir was emptied in October 2000, several operations being performed: longitudinal and transversal drainage of the berm, local repairing of the concrete face joints sealing and filling the exfiltration funnel at km1+276. As a result, the exfiltration at km0+790 and km1+670 were put out for good and the one at km1+300 seized to run on for a short period of time (80 days), reappearing with about 50% from its previous rate. The water level correlated exfiltration evolution, mentioning also two intervention moments (the natural generated one and the technological one), is presented by figure 2.

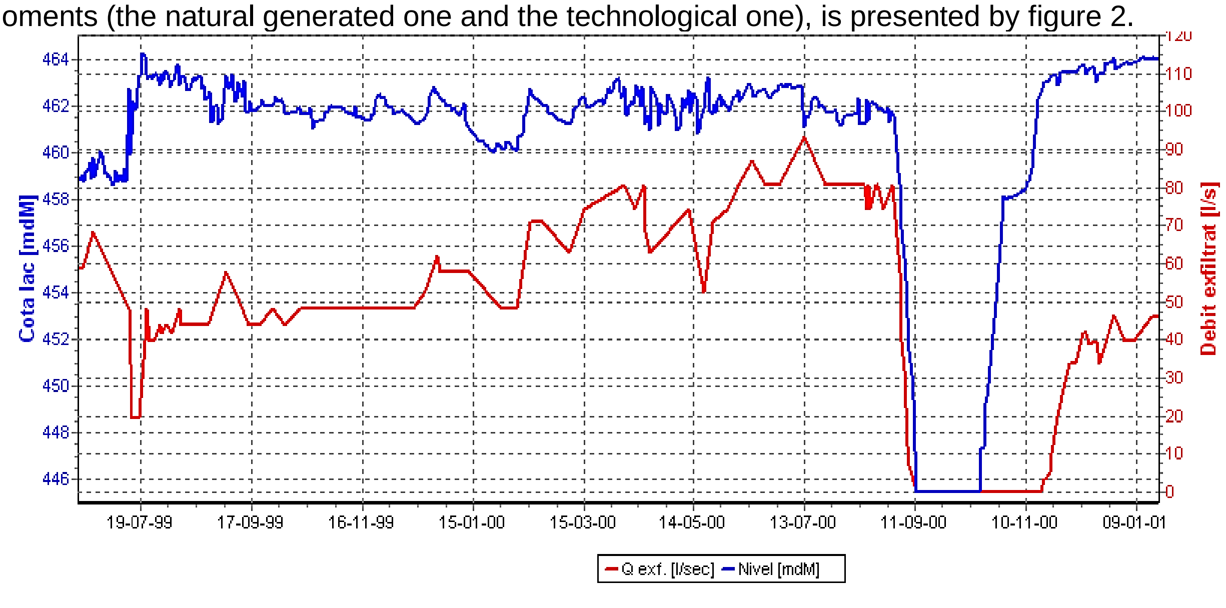


Fig. 2. Correlated exfiltration development on the left bank embankment of Ostrovul Mic reservoir

Given the importance of this also interesting subject, the present paper aims to bring on the light an approach method for sealing deficiency turnaround in the zone of km1+300 at the left side embankment of Ostrovul Mic water reservoir. An interception drain is suggested at the bottom level of the embankment downstream face while the infiltration discharge is then checked by a 2D numerical model on which several accompanying works are considered.

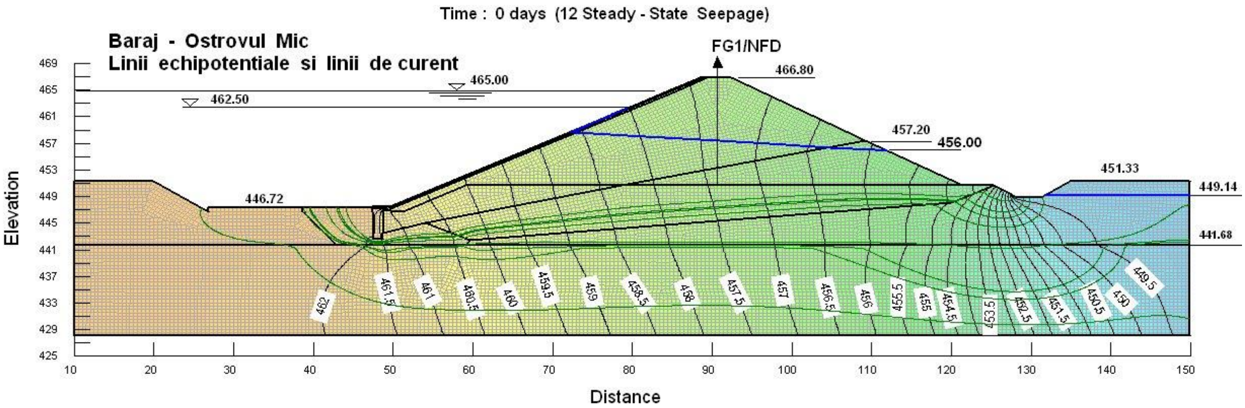
2. Wedging the numerical model under stationary and transitory regimes

The numerical model of the study case was built following the boundary conditions according to data appropriately supplied by the owner of Raul Mare – Downstream water arrangement [1]. These conditions include results obtained by measurements performed by infrared photography technics [2]. The outgoing levels of infiltration curve – from 456.00 to 457.20 mSL [4] – was established by analysing the thermal investigations results. Consequently, the numerical model was attuned with respect to the material permeability and anisotropy [5] based on this available data. This stage of the numerical study was performed both for the stationary and transitory regimes as presented here. The corresponding three established basic situations were as follows:

a. Stationary regime – developed for the fixed water level of 462.50 mSL in the Ostrovul Mic reservoir (figure 3)

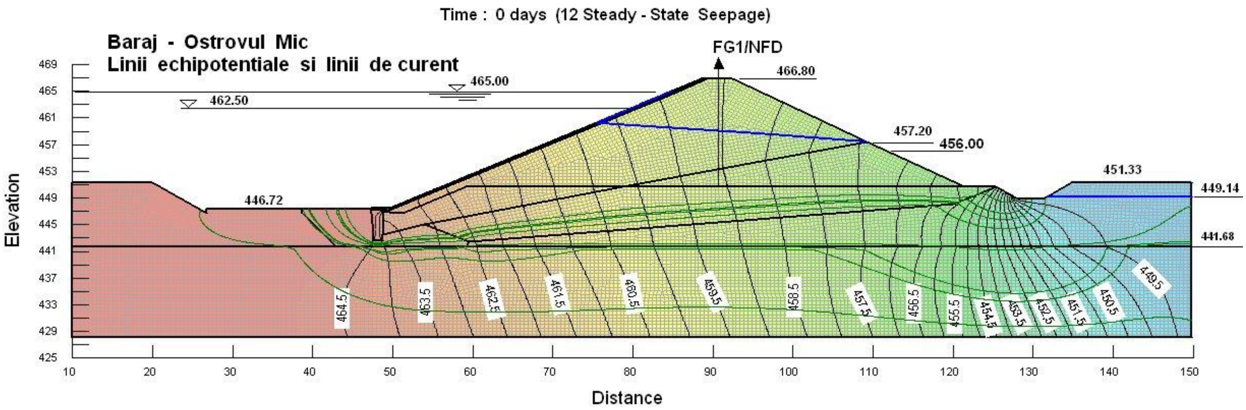
b. Stationary regime – developed for the fixed water level of 465.00 mSL in the Ostrovul Mic reservoir (figure 4)

c. Transitory regime – developed for a maximum initially water level in the Ostrovul Mic reservoir imposed at 462.30 mSL (figure 5)



1		0 days						
2	Distance	Water Flux (m³/days)			Nivel in lac=		462.5	mdM
3	0	-696.212						
4	0.551981	-391.884			-300.304			
5	1.067746	-207.388			-154.542			
6	1.583511	-145.048			-90.8872			
7	2.099277	-113.617			-66.7052			
8	2.615042	-93.5043			-53.4129			
9	3.130807	-80.3007			-44.8213			
10	3.646572	-81.1091			-41.6248			
11	4.168245	-33.791			-29.9702			
12			Qtotal_exf_contracai		-782.27	mc/zi =	-9.054	l/s

Fig. 3. Equipotential and flow current lines corresponding to the upstream level of 462.50 mSL



1		0 days					
2	Distance	Water Flux (m³/days)		Nivel in lac la =	465	mdM	
3	0	-824.109					
4	0.551981	-463.874		-355.471349			
5	1.067746	-245.486		-182.931594			
6	1.583511	-171.694		-107.5834858			
7	2.099277	-134.489		-78.95921155			
8	2.615042	-110.681		-63.22503963			
9	3.130807	-95.0522		-53.0551139			
10	3.646572	-96.0091		-49.27137345			
11	4.168245	-39.9986		-35.47578577			
12			Qtotal_exf_contracana	-925.9729532	mc/zi =	-10.717	l/s

Fig. 4. Equipotential and flow current lines corresponding to the upstream level of 465.00 mSL

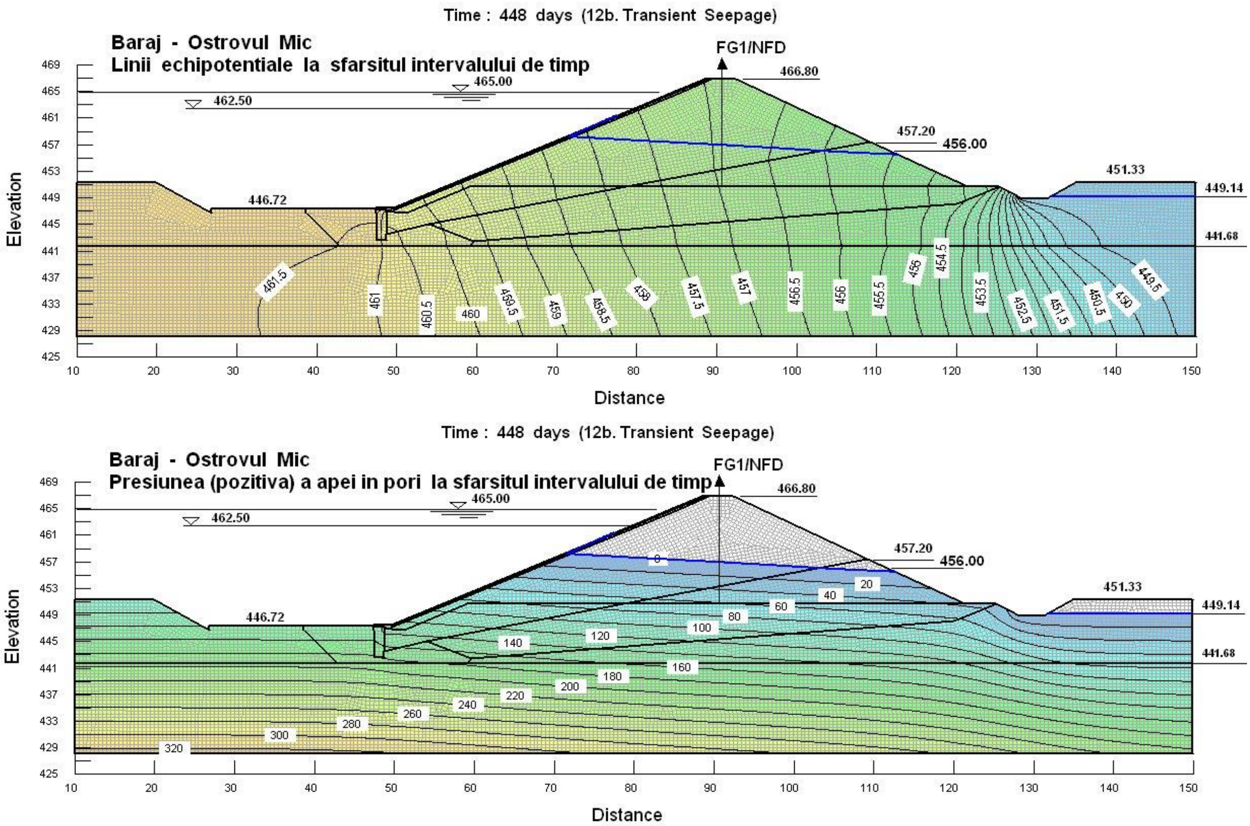


Fig. 5. Equipotential lines and pore water pressure at the end of the transitory phenomenon time interval 24.10.2013 - 18.03.2015

The following figure 6 shows the correlated water levels in the reservoir and observation well FG1/NFD along the given monitoring time interval.

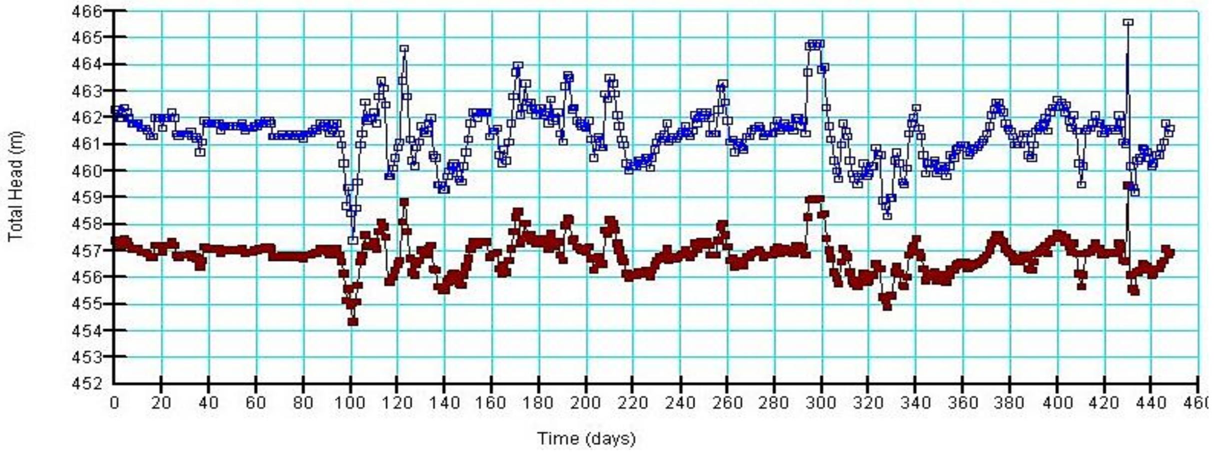


Fig. 6. Reservoir water level development with time and corresponding level in the monitoring well FG1/NFD along the given time interval 24.10.2013 - 18.03.2015

The figure 7 shows the comparative development of the reservoir water levels and the measured (supplied by the owner of the water arrangement) and model calculated water levels in the observation well for the mentioned monitoring (analysis) time interval.

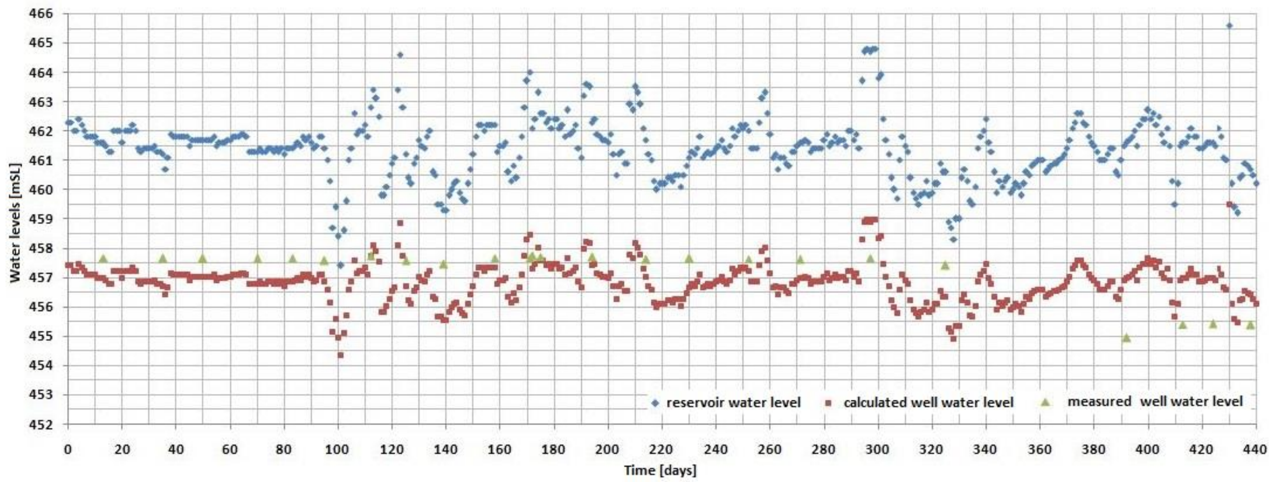
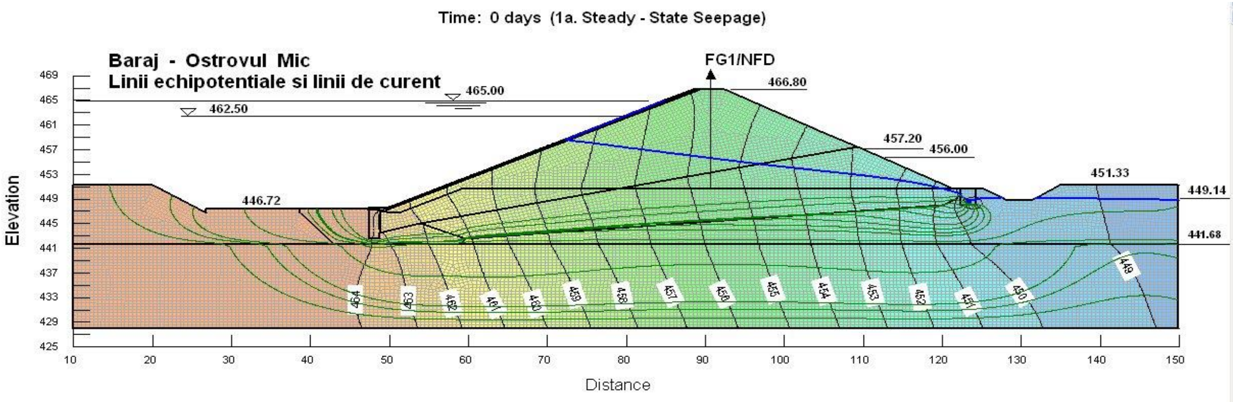


Fig. 7. Measured and calculated well water levels correlated with the reservoir water levels development along the monitoring time interval 24.10.2013 - 18.03.2015

3. Numerical modeling of the suggested solutions for turning around the embankment sealing deficiency

3.1 Downstream drain, without upstream intervention in the water reservoir

Looking to lower the infiltration curve, a side longitudinal drain (perforated pipe of 318mm in diameter) was considered with the 2D numerical model. By considering the stationary regime for the reservoir usual water level of 465.00 mSL, the model led to a decreased infiltration curve and an exfiltrated specific discharge of 3.828 l/s/m (figure 8, as to see with respect to basic data given by figure 4).



1		0 days					
2	Distance	Water Flux (m³/days)		Nivel lac NNR =		465	mdM
3	0	-699.885					
4	0.095273	-515.041		-57.875			
5	0.180976	-461.451		-41.8441			
6	0.271632	-423.757		-40.1248			
7	0.366623	-352.126		-36.8506			
8	0.466628	-241.276		-29.6716			
9	0.5598	-164.207		-18.8898			
10	0.658415	-151.134		-15.5487			
11	0.748042	-179.263		-14.8062			
12	0.829613	-248.644		-17.4525			
13	0.917009	-330.324		-25.2995			
14	1.000746	-444.411		-32.4373			
15			Qtotal_exfiltrat=	-330.8	mc/zi =	-3.828	l/s

Fig. 8. Equipotential and flow current lines corresponding to the upstream level of 465.00 mSL in case of lowering the infiltration curve by the help of a downstream drain

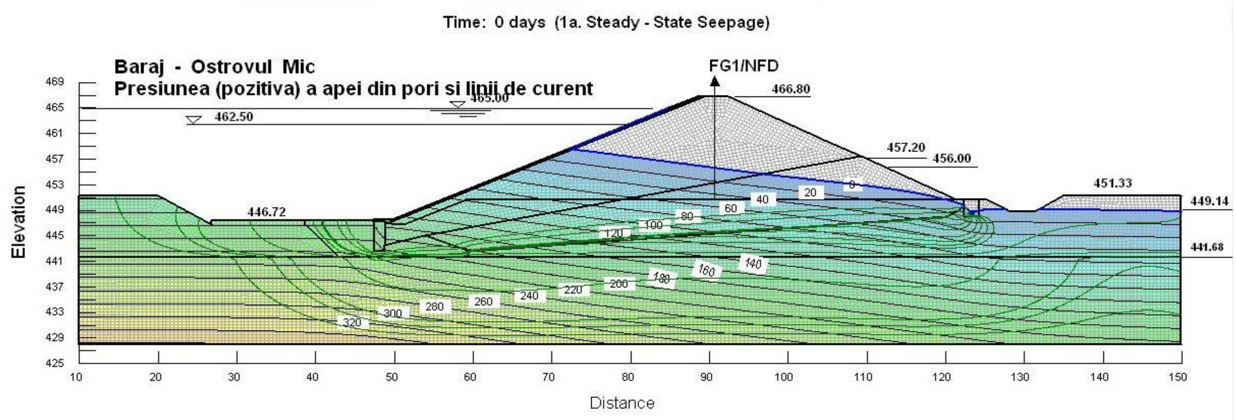
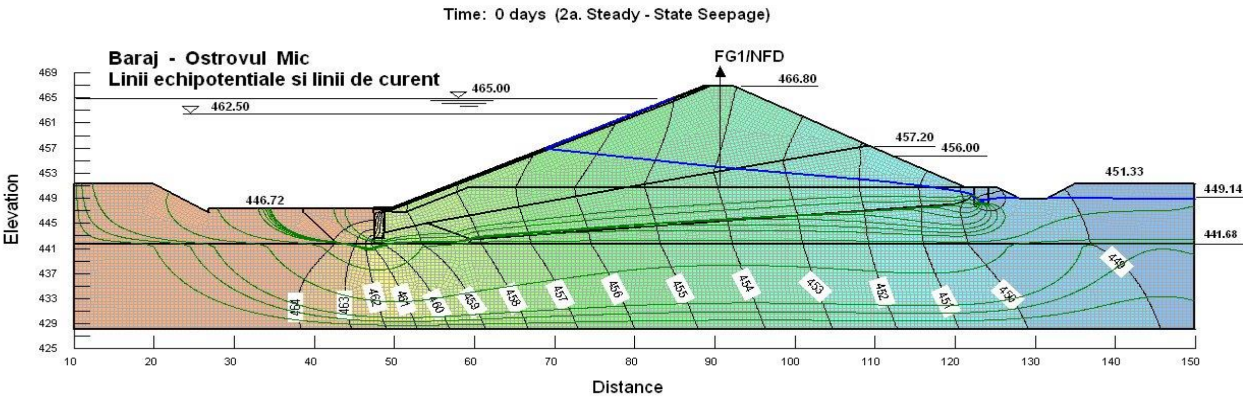


Fig. 9. Pore water pressure and flow lines by considering a downstream drain

3.2 Downstream drain and consequent upstream warping, without upstream intervention in the water reservoir

There is considered the warping effect given by the reduced flowing velocities in the funnel zone due to the lowered infiltration curve. Alluvia settlement is determined in time which concludes in permeability reduction (similar to warping produced by the fine material brought by high waters). This modeled phenomenon leads to an exfiltrated specific discharge of 2.836 l/s/m (figure 10).



1		0 days						
2	Distance	Water Flux (m³/days)			Nivel lac NNR=		465	mdM
3	0	-638.688				Kcolmatat=		
4	0.095273	-451.861			-51.9501			
5	0.180976	-384.647			-35.8456			
6	0.271632	-326.806			-32.2488			
7	0.366623	-233.451			-26.6095			
8	0.466628	-110.747			-17.2108			
9	0.5598	-40.6399			-7.0525			
10	0.658415	-54.6442			-4.69824			
11	0.748042	-113.573			-7.53841			
12	0.829613	-192.302			-12.4753			
13	0.917009	-283.174			-20.7771			
14	1.000746	-398.786			-28.5529			
15			Qtotal_exfiltrat=		-244.96	mc/zi=	-2.836	l/s

Fig. 10. Equipotential and flow current lines corresponding to the upstream level of 465.00 mSL in case of lowering the infiltration curve and assuming alluvia warping in the funnel

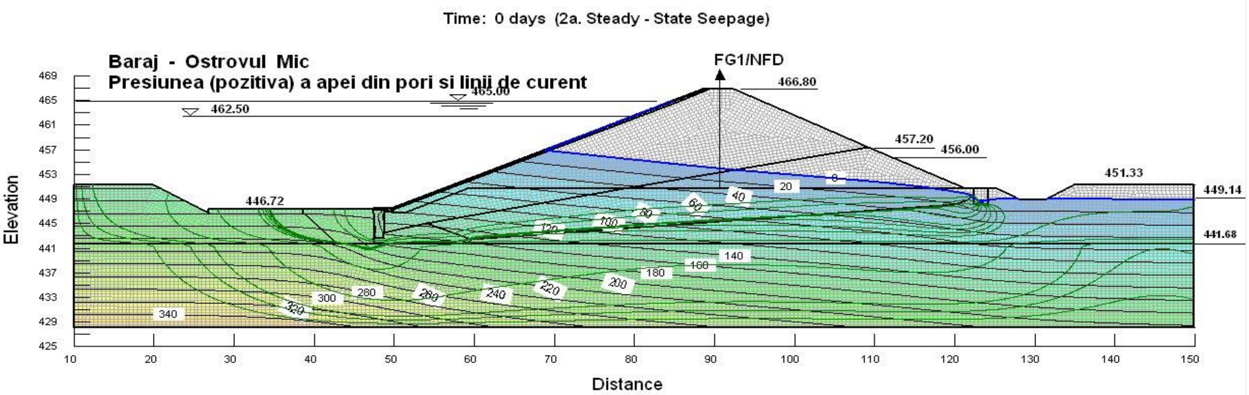
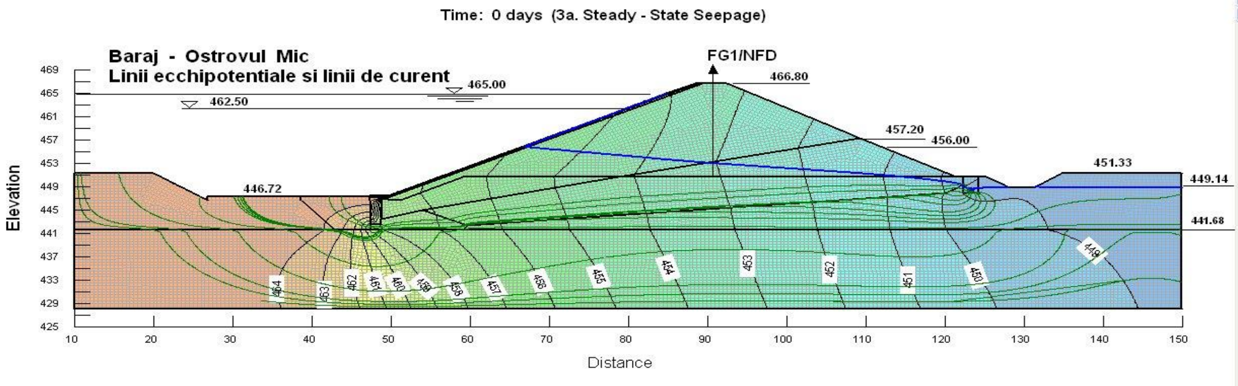


Fig. 11. Pore water pressure and flow lines by considering a downstream drain and the warping phenomenon

3.3 Downstream drain and superficial filling operation of the upstream funnel

Accompanying the drain accomplishment, in order to reduce the embankment seepage a mechanized filling of the existing exfiltration funnel is proposed. This operation can be developed either with or without emptying the reservoir, by adopting corresponding technologies.

By considering a compacted earthfill, the numerical modeling led to an exfiltrated specific discharge of 2.31 l/s/m (figure 12).



1		0 days						
2	Distance	Water Flux (m³/days)			Nivel lac NNR=		465	mdM
3	0	-606.341						
4	0.095273	-418.466			-48.8183			
5	0.180976	-344.05			-32.6749			
6	0.271632	-275.561			-28.0858			
7	0.366623	-170.722			-21.1963			
8	0.466628	-41.7522			-10.6243			
9	0.5598	24.67519			-0.79555			
10	0.658415	-3.64203			1.037097			
11	0.748042	-78.8509			-3.6968			
12	0.829613	-162.52			-9.8445			
13	0.917009	-258.252			-18.3867			
14	1.000746	-374.669			-26.4997			
15			Qtotal_exfiltrat=		-199.59	mc/zi =	-2.31	l/s

Fig. 12. Equipotential and flow current lines corresponding to the upstream level of 465.00 mSL in case of considering a downstream drain and upstream funnel filling

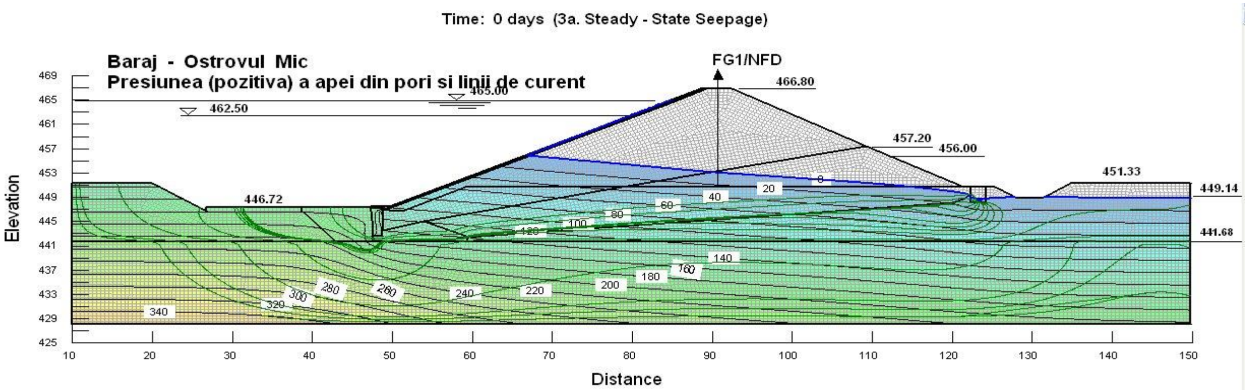
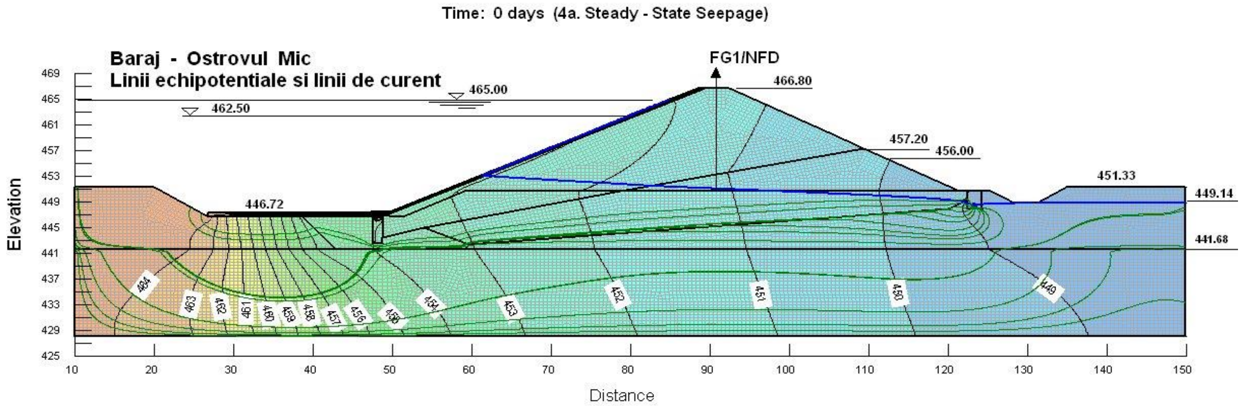


Fig. 13. Pore water pressure and flow lines by considering a downstream drain and the upstream funnel filling

3.4 Downstream drain and upstream bottom sealing structure

There is suggested a major intervention upon the upstream sealing solution by an extension with a bottom fore-raft structure, either as a concrete rigid one or an elastic one of gabions. The exfiltrated specific discharge was obtained in this case of 1.12 l/s/m (figure 14).



1		0 days						
2	Distance	Water Flux (m³/days)			Nivel in lac =		465	mdM
3	0	-533.051						
4	0.095273	-342.801			-41.722623			
5	0.180976	-252.07			-25.491072			
6	0.271632	-159.453			-18.653511			
7	0.366623	-28.5965			-8.9314099			
8	0.466628	114.57			4.2988882			
9	0.5598	172.6606			13.380908			
10	0.658415	111.9145			14.031745			
11	0.748042	-0.18017			5.0072047			
12	0.829613	-95.0443			-3.8837995			
13	0.917009	-201.784			-12.970689			
14	1.000746	-320.028			-21.847673			
15			Qtotal_exfiltrat=		-96.782	mc/zi =	- 1.12	l/s

Fig. 14. Equipotential and flow current lines corresponding to the upstream level of 465.00 mSL in case of considering a downstream drain and an upstream bottom sealing structure

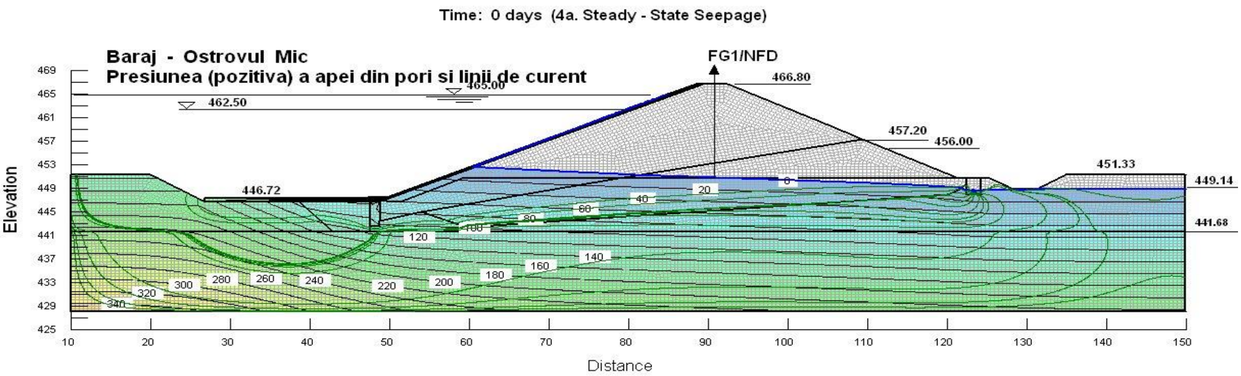


Fig. 15. Pore water pressure and flow lines by considering a downstream drain and an upstream bottom sealing structure

4. Conclusions

As the reached 2D model graphic representation show, the infiltration flow is lowered towards the downstream interception drain (perforated pipe). The modeled exfiltration from the funnel zone is considerably reduced, the situation being even more improved by the upstream accompanying works. As expected, the major upstream intervention by extending the sealing structure with a bottom fore-raft shows the most drastic reduction of the existing exfiltration problem, but the economic aspect should be also considered by a specific feasibility study in order to decide towards the optimum solution.

The 2D numerical modeling of the embankment infiltration phenomenon for the most radical structural intervention leads to a drop in the exfiltrated specific discharge from a value of 10.717 l/s/m to a value of 1.12 l/s/m, while the outgoing infiltration curve level reaches well in the alongside existing safety counter duct. As considering the reservoir usual water level of 465.00 mSL, the outgoing level actually below the downstream ground level would thus ensure the safety running of Ostrovul Mic water development.

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