Fish Ladder Numerical Modelling

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The paper presents a 1D numerical modeling of the sanitary water flow passing through a fish ladder designed for the low head step built across the Alb (White) River near Coroiesti Vilage in Hunedoara County. The model aims to evaluate the water velocity spectrum, emphasizing the maximum values, in the cross sections along this passing structure and in the same time to establish the water levels development. In order to reach this goal, the numerical model will consider a sinthetical hydrograph based on the maximum value of the sanitary water flow required on the river.

Keywords: 1D numerical modeling, fish ladder, sinthetical hydrograph, sanitary water flow

The design and implementation of engineering solutions for water courses must take into account their dynamics and respect the known ecological concepts whereby the water course is considered a continuous system with hydrological connectivity (longitudinal, lateral and vertical) and variable in time [1, 2]. In order to diminish the negative impact on the environment, water solutions will be promoted taking into account, in addition to the technical and economic and social aspects, a series of principles and criteria specific to the area and / or river basin for the conservation of nature and biodiversity [1].

The specific development *Fish intensive farming and fish processing hall* [3] assumed the accomplishment of a sidebank water catchment requiring also a low head overflowing step ending with a water energy dissipater (fig.1), these hydraulic structures being situated at the level of 641.50mSL on a branch of the Alb River [4] about 500m upstream of Coroiesti Hamlet (as part of Salasul de Sus Vilage) in Hunedoara County. Additionally, according to nowadays legislation regarding such water arrangement of fish farming employment, a corresponding fishway structure was proposed in order to preserve the natural passing.

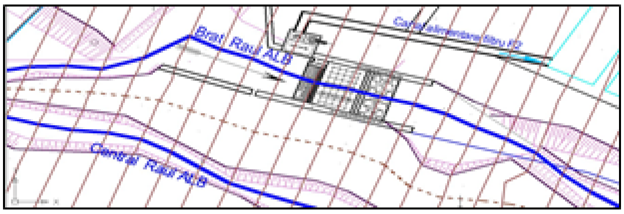

Fig. 1. Layout of hydraulic structures: sidebank catchment, low head overflowing step and energy dissipater -Alb River branch

The explicit dimensions of the comprising hydraulic structures are employed by a previous numerical study upon the water discharge [5] as given by [3].

As about dimensioning the structure proposed as fish ladder, the water flow along the river branch was estimated to reach the value $Q_{branch} = 0.5387\ m^3/s$, while the required sanitary flow corresponding to normal operating conditions would reach the maximum value of $Q_{sanitary} = 0.120\ m^3/s$.

In order to perform the numerical modeling of the sanitary water discharging by a fish passing, the authors proposed a ladder structure with the geometry indicated by figure 2.

Depending on the species of fish monitored on the water course, conditions are required for design planning the fish passages (for example: maximum flow velicities, maximum height of the thresholds).

The flow rates of water across long and uniform sections within a passage structure should be less than sustained speed and long distance jumping / (burst speed), characteristic for each species (FAO/DVWK, 2002, [6]). The inlet area in the upstream and downstream passage structure must be determined according to the hydrological conditions existing in the reservoir and the natural place of aggregation of the fish. From the point of view of fish micro-habitat preferences, they tend to gather in the lake areas where water recirculation takes place [7].

To estimate the required depth of water along the fish scale, data from specialized studies on micro-habitat preferences of species found in the studied sector were collected and analyzed [8]. Although these data clearly refer to the target species, it is important to note that these data were collected from studies conducted on natural or semi-natural areas of the rivers, not on anthropogenic structures such as fish scales. A case study of two ramp passes on the Enz river, used passages, and individuals of the Cottus gobio species, provide for the depth of the water column to be between 0.2 and 1 meter (Jansen, Kappus, Böhmer & Beiter, 1999, [9]).

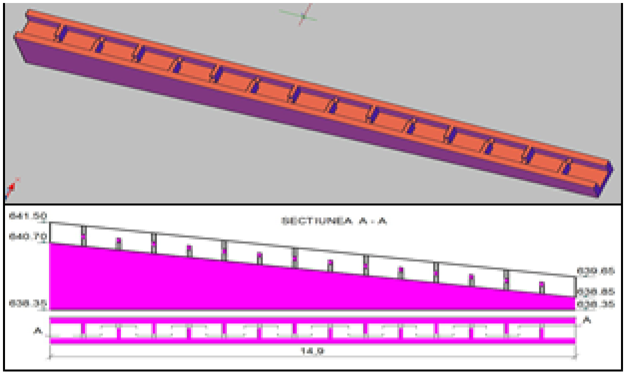

Fig. 2. Fish ladder structure - overall 3D view, longitudinal crossview, planview

A sinthetical configuration available through HEC-RAS v5.03 software package [10] was engaged in order to generate the ladder structure passing hydrograph as a high waters curve of 0.120 m^3/s toping value (enforced by the sanitary conditions).

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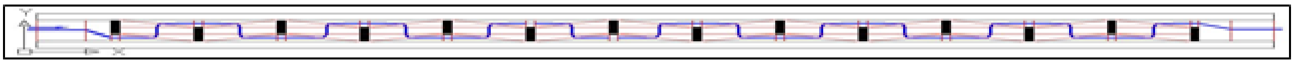


Fig. 3. Projected planview of the fish ladder stepped channel indicating the flow route and the main crosspaths position

The proposed fish ladder concrete structure of a mean slope of about 12.4% represents a rectangular rapid channel with the cross section B=0.6m x H=0.8m divided by crossing thin stepping walls in 15 compartments. The 14 crossing walls of about 15cm in thickness are sidely breached both at the top and at the bottom, the openings alternating in order to move the water current from one side to the other. The top gap (e.g. b=20cm x h=35cm) can be considered to work as a broad crested spillway, while the bottom opening (e.g. b=18cm x h=27.5cm) would work as a rectangular aperture.

Figure 3 presents the stepped channel sloping projection as needed for the numerical modeling by the help of HEC-RAS v5.03, indicating also the mean current line of the water flowing down the fish ladder.

The numerical model of the structure geometry, according to graphical reprezentations developed in AutoCAD, was accomplished by the help of a 3D database comprising the planview together with 85 crosspaths along the entire flow route that highlight the geometrical shape and the sides and floor material roughness.

Experimental part

As a common procedure with a flow modeling, the crosspaths identification is undertaken by a standard milestone counting, specifically a designation by a numerical value representing a real number [11, 12]. This is a very useful procedure for generating new interleaved crosspaths (thickening certain path lengths) by automatic interpolation or by different interpolation methods between two initial consecutive cross sections, given from topographic measurements or other technical editing.

By proceeding with the operations for generating geometry characteristics from the previously created database, followed by the enrichment with additional interpolated crosspaths, the graphical representation presented by figure 4 was obtained, with a crosspaths spacing of about 10cm.

In order to simulate a broad crested spillway with a rectangular bottom opening, there was considered a *bridge* type crossing structure [10] according to the specific characteristics along the path of the model.

The figure 5 presents the cross section geometrical characteristics for the usual channel dividing wall, while the figure 6 presents the geometrical and hydraulic characteristics for the considered broad crested spillway with a discharge coefficient of m_d=0.313. The geometrical and hydraulic elements of the current bottom opening (rectangular outlet) are indicated by figure 7.

Results and discussions

So as to reach the proper option for the spillway - bottom outlet ensemble, several levels were considered, both for the spillway crest and for the opening top. The present paper brings up only two situations that both lead to a favourable result, which from the optimum configuration was afterwards pointed out. The two situatins regarding the spillway crest are h_{culv1}= 0.300m and h_{culv2}= 0.275m, while regarding the height of the crossing beam (as defining the bottom opening height) they are h_{beam1}= 0.150m and h_{beam2}= 0.175m (the overspilling crest resting so at the same level).

The roughness coefficients distribution is taken as a constant, both around a given crosspath and from one crosspath to the other, the proper considered value of it for the concrete channel being n = 0.015.

Fig. 4. Planview of the numerical model

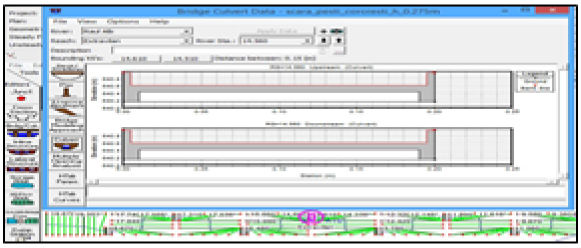
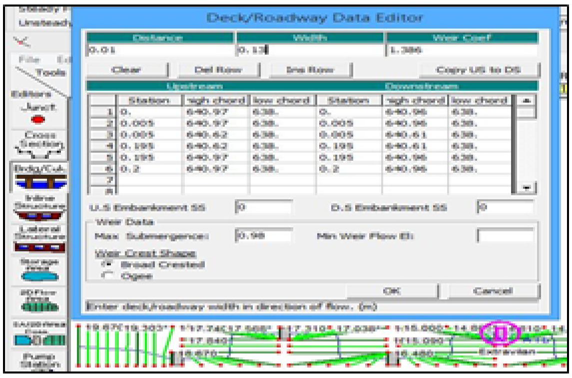


Fig. 5. Crossing structure *Bridge* modeling the current dividing wall, upstream and downstream faces



Distance	Width	Weir Coef
0.01	0.13	1.386

	Upstream			Downstream		
	Station	high chord	low chord	Station	high chord	low chord
1	0.	640.97	638.	0.	640.96	638.
2	0.005	640.97	638.	0.005	640.96	638.
3	0.005	640.62	638.	0.005	640.61	638.
4	0.195	640.62	638.	0.195	640.61	638.
5	0.195	640.97	638.	0.195	640.96	638.
6	0.2	640.97	638.	0.2	640.96	638.
7						
8						

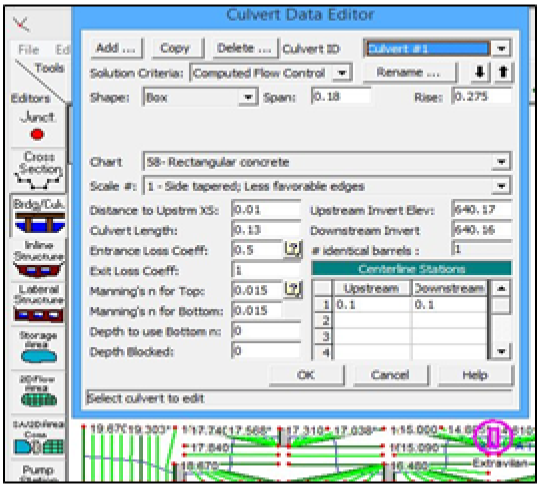
U.S Embankment SS: 0
D.S Embankment SS: 0

Weir Data
Max Submergence: 0.98
Min Weir Flow El:

Weir Crest Shape
● Broad Crested
○ Ogee

Enter deck/roadway width in direction of flow. (m)

Fig. 6. Crossing structure *Bridge*, geometric and hydraulic elements for a broad crest spillway of m_d=0.313 discharge coefficient



Culvert ID: Culvert #1
Solution Criteria: Computed Flow Control
Shape: Box
Span: 0.18
Rise: 0.275
Chart: 58- Rectangular concrete
Scale #: 1 - Side tapered; Less favorable edges
Distance to Upstrm XS: 0.01
Culvert Length: 0.13
Entrance Loss Coeff: 0.5
Exit Loss Coeff: 1
Manning's n for Top: 0.015
Manning's n for Bottom: 0.015
Depth to use Bottom n: 0
Depth Blocked: 0
Upstream Invert Elev: 640.17
Downstream Invert: 640.16
identical barrels : 1

Centerline Stations

	Upstream	Downstream
1	0.1	0.1
2		
3		
4		

Select culvert to edit

Fig, 7. Crossing structure *Bridge*, geometric and hydraulic elements for a current bottom outlet (opening)

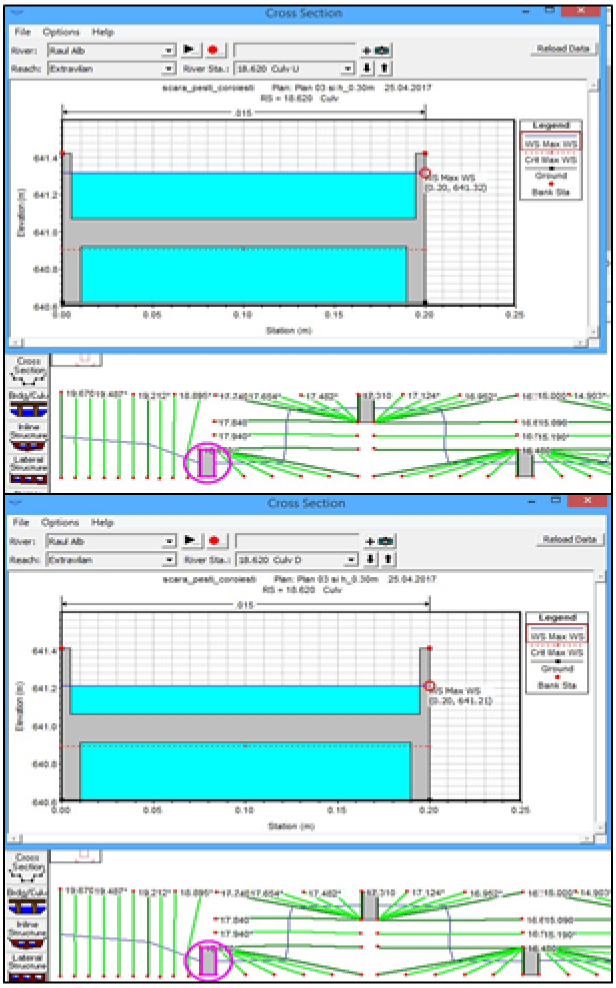


Fig. 8. The piezometric line at the up- (Culv U) and downstream (Culv D) faces of the *bridge* structure 18.620, as for the maximum of *regime* R1

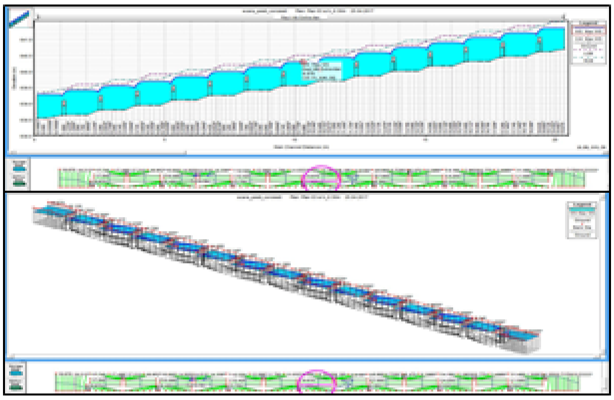


Fig.9. The 1D and 3D longitudinal flow development along the fish ledder structure, as for the maximum of *regime R1*

The further on described numerical modeling covers the water discharge simulation as an unsteady flow regime for the two slightly different geometric proposals for the stepping walls.

As a common procedure for the actual running of such a model, the boundary conditions are given by the flowing discharge considered as a synthetic highwaters hydrograph with its values attached to the upstream entering crosspath (the metric stone *19.760*), and the hydrodynamic grade corresponding to the rivercourse immediately downstream of the discharging structure, with its value attached to the outgoing downstream crosspath (J=0.105‰ at the metric stone *0.100*). As an initial flow condition, the water discharge known as $Q=0.080$ m^3/s was considered for the entering upstream crosspath designated as the metric stone *19.760*.

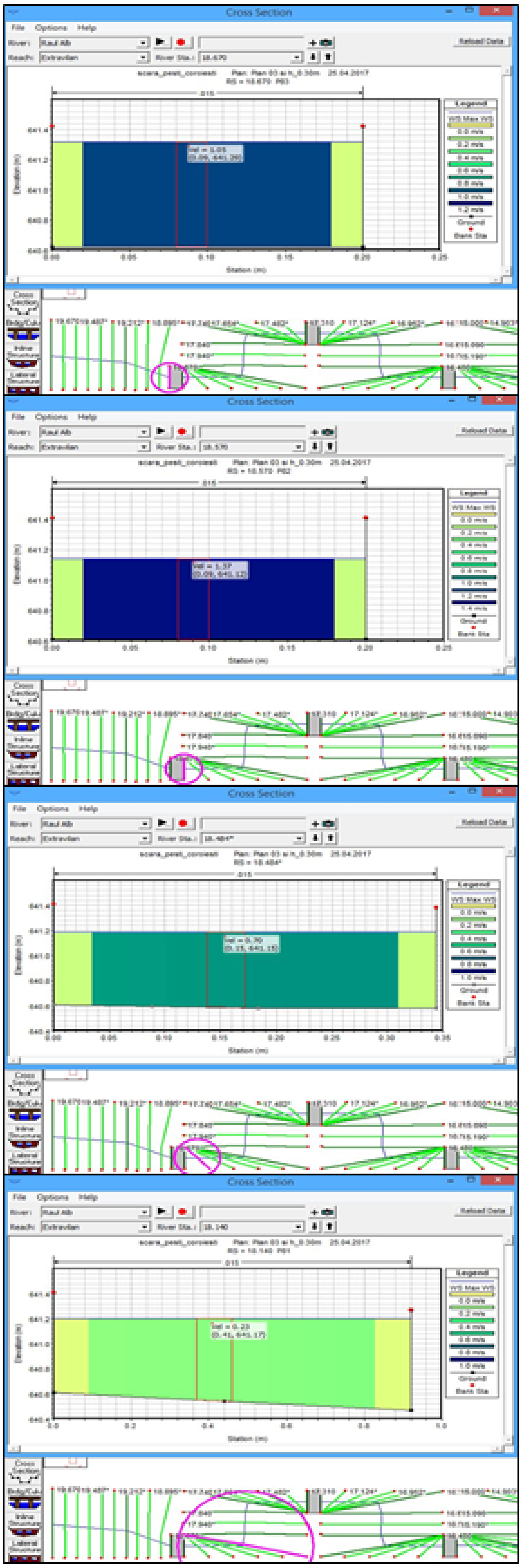


Fig. 10. Velocity spectrum and piezometric lines at P83 –18.760, P82 –18.570, 18.484* and P81 –18.140, as for the maximum of *regime* R1

Following the model running, the next constant or time developing parameters were produced in all the considered crosspaths for the two mentioned geometric situations: water levels, discharges and velocities.

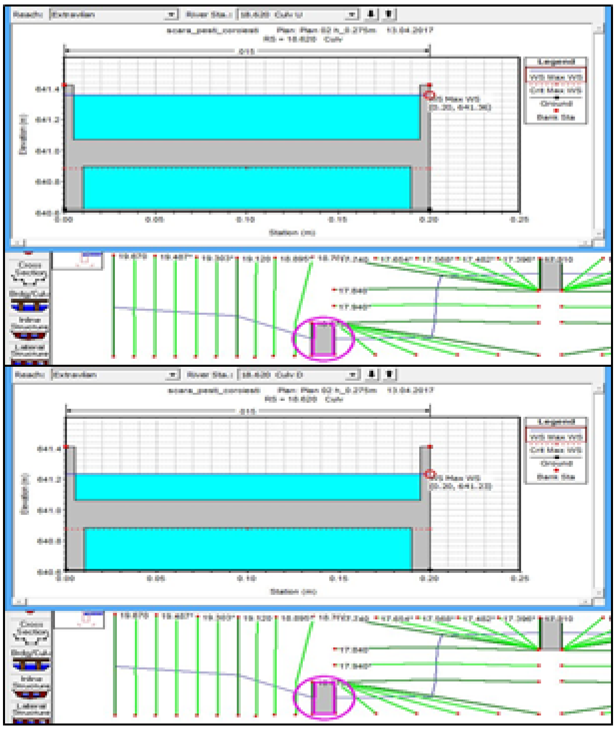


Fig. 11. The piezometric line at the up- (Culv U) and downstream (Culv D) faces of the *bridge* structure 18.620, as for the maximum of *regime* R2

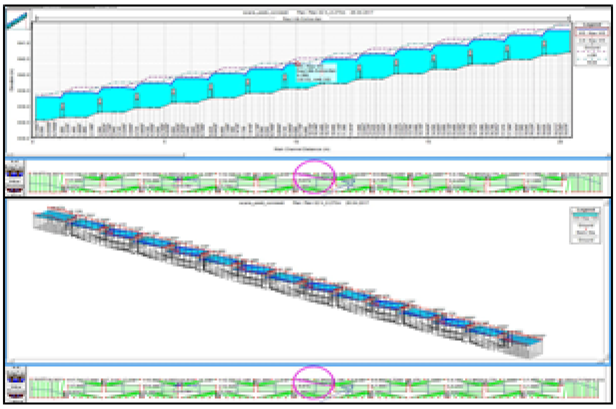


Fig. 12. The 1D and 3D longitudinal flow development along the fish ledder structure, as for the maximum of *regime* R2

a) The unsteady water flow regime-**R1** corresponding to stepping walls geometry defined by b_{culv}=0.180m, h_{culv1}=0.300m and h_{beam1}=0.150m, and for which the maximum value of the required sanitary flow shall be $Q_{sanitary}$= 0.120m^3/s.

The results reached by the graphic postprocessing are partially described further on:

· the piezometric lines (the water level as mSL) at the up- and downstream faces of the *18.620* structure (the first upstream stepping wall, fig.8) and for several other significant crosspaths (P83, P82, *18.484**, P81), together with the corresponding velocity spectrum (in m/s, fig. 10);

· the longitudinal view covering the characteristic geometry (thalweg, left/right sidewalls, stepping structures) and showing the piezometric line extension (presented both as 1D and 3D views) for the maximum flow of regime R1 (fig 9).

b) The unsteady water flow regime -, **R2** corresponding to stepping walls geometry defined by b_{culv}=0.180m, h_{culv2}=0.275m and h_{beam2}=0.175m, and for which the maximum value of the required sanitary flow shall be the same $Q_{sanitary}$= 0.120m^3/s. The similar results reached by the graphic postprocessing are indicated by figures 11-13.

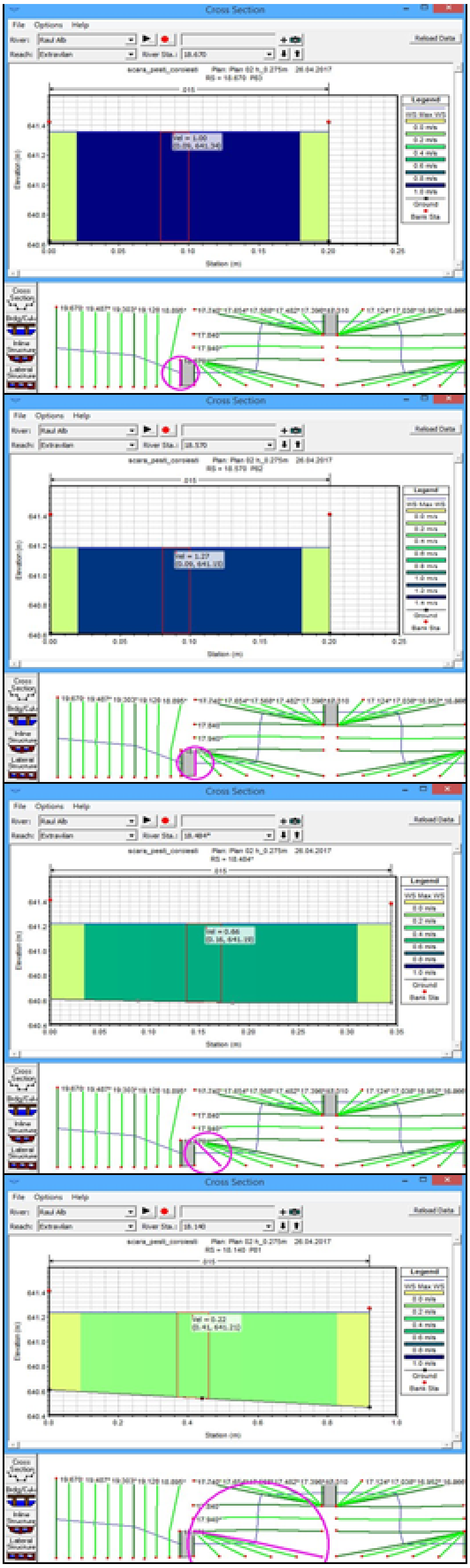


Fig. 13. Velocity spectrum and piezometric lines at P83-*18.760*, P82 -*18.570*, *18.484** and P81 -18.140, as for the maximum of *regime* R2

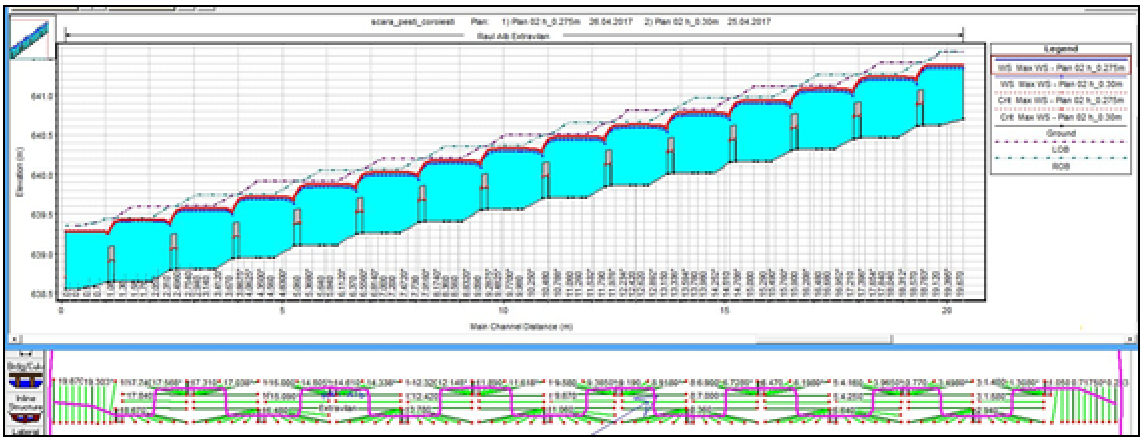


Fig. 14. Comparativ longitudinal 1D flow views along the fish ledder structure, as for the maximum discharge of *regime* R1 and *regime* R2

Conclusions

As studying the reached results from the graphical representations, one can notice that the water discharge corresponding to the situation designated as *regime R1* leads to water level variations below to those corresponding to *regime R2.* Figure 14 comparatively presents the water levels extensions for the two situations along the entire fish ledder proposed structure, both corresponding to the maximum discharge value.

Similarly, figure 14 presents the water level variation at a current stepping *bridge* structure (up- and downstream faces of *11.840*), while figure 15 shows the water level variation and velocity spectrum at the same stepping wall (meaning crosspath P53 for its upstream and crosspath P52 for its downstream).

By considering the graphical representations in figures 8 and 11, the following values of water velocities and levels come out according to the flowing regimes (table 1).

Table 1

Crt. no.	designation	crosspath	regime	Velocity (m/s)	level (mSL)
1	“18.840”	P53	R1	1.05	641.29
			R2	1.00	641.34
2	“18.570”	P52	R1	1.37	641.12
			R2	1.27	641.15
3	“18.484”	-	R1	0.70	641.15
			R2	0.66	641.19
4	“18.140”	P51	R1	0.23	641.17
			R2	0.22	641.21

There can also be noticed that water velocity values are slightely lower for *regime R2* with respect to those for *regime R1* while the corresponding levels rise a bit higher.

As about the stepping walls configuration, the overspill and the bottom outlet determin two colliding water veins that so dissipate the hydraulic energy downstream of each crossing structure at the level of the *fish resting* basins. As we can say, the way of accomplishing the hydraulic energy dissipation, the general velocity spectrum and the fact that the water levels do not overpass the delimitating sidewals lead to the main conclusion that the fish ledder structure as a hole is properely arranged.

Further more, by considering the specific results of the performed numerical simulations seeing the maximum required sanitary flow $Q_{sanitary} = 0.120 m^3/s$, at this point we may conclude from the double set of values that the optimum geometric situation for the proposed fish ledder structure would be the one leading to lower velocity values

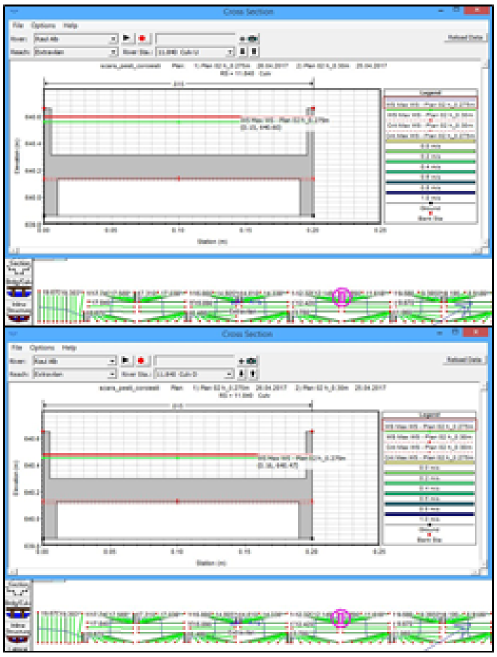


Fig.15. Piezometric lines comparison for a current stepping wall, up- (Culv U) and downstream (Culv D) of *11.840,* as for the maximum discharge of *regime* R1 and *regime* R2

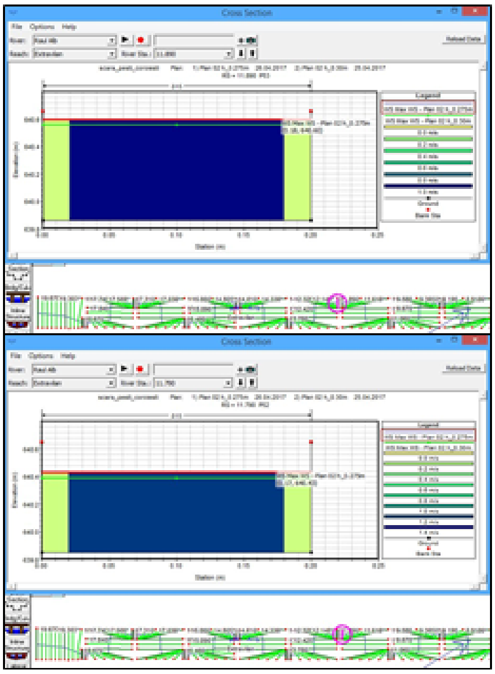


Fig. 16. Piezometric lines comparison and velocity spectrum in the immediate vicinity of the current stepping wall (upstream P53 - *11.890* and downstream P52 - *11.790*), as for the maximum discharge of *regime* R1 and *regime* R2

and higher water levels, meaning the alternative designated as r*egime R2*: the bottom opening through the stepping wall b_{culv}=18cm x h_{culv}=27.5cm (corresponding to a crossing beam height of h_{beam}=17.5cm) and the top spilling gap b_{spill}= 20cm x h_{spill}= 35cm.

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