Computer Modelling of an Aquatic Fauna Complex Concrete Passage at a River Barrage

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Abstract: *The paper presents a 2D computer structure modelling and discharge simulation for an improved aquatic fauna passage consisting on a three compartments stepped concrete channel and considered as a side appurtenant for a small head dam on a river upper course. The foreseen structure aims to reduce the barraging environmental impact by offering optimum flow conditions under given water discharging circumstances, meaning even for ensuring the minimum required sanitary/ecological river discharge as split by the main path through the gate dam and the side passage path. The hydraulic simulation looks to establish the side passage discharge development and in the same time to estimate the extreme values of water velocity, especially at narrowing sections. In case there is necessary, the numerical results would point to further geometrical optimisation by adjusting the existing structural details or by considering additional constructive elements in order to fulfil specific requirements (usually with respect to the maximum water velocities) as indicated by in-force regulations.*

Keywords: *Fish ladder, hydraulics, numerical model.*

1. General presentation of the studied structure

The water arrangement on the Livezeni–Bumbești mountainous sector of Jiu River [1,2], Hunedoara County, Romania, is mainly designated for hydro-power harnessing. The considered developed river area is situated between the East Jiu and West Jiu Rivers confluence (right south of Petroșani Town) and the confluence with left side Valea Sadului River tributary (towards the Town of Bumbești Jiu), stretching over about 31km in the Jiu Gorges. The Livezeni hydro-power development consists from the Livezeni Dam – a three radial gate controlled 12m gaps spillway barrage of 9m height and about 45m wide, creating an about 130000m^3 accumulation and endowed with water power dissipater and a left side fish ladder channel – placed on the gorges upstream entry, the water-power catchment with an underground silting basin, the 6900m length headrace of 3.80m diameter, the underground 24m height surge-tank, the gate house sheltering a high capacity butterfly valve, the 142m length and 2.95m inner diameter steel penstock and the 36m3/s installed flow and 24.5MW installed power Dumitra Power Station (surface) fitted with three Francis groups. The sanitary flow required on the river sector immediately downstream of the dam for ecological conditions is 2.70m^3/s.

As designed by S.C. ISPH Project Development S.A. (Hydropower Designing and Studies Institute), Bucharest, the fish passage is a concrete structure accomplished by three zones (counting in the flow direction) [1,2], the third one, as considering the upstream fish migration, being designed for fauna comfort and accommodation. At its lowest end, the side passage is connected by a rectangular free side window (about 1.95m wide by 2.40m height at the level of 539.60mSL) to the staggered blocks apron of the water energy dissipater (fig.1).

The further on presented numerical discrete modelling of the flowing phenomenon by the Livezeni Dam side fish ladder aimed to detail and enhance its initial general geometry for the structure elements, based on water velocity development as revealed over the entire 2D domain and with a closer look towards the path narrowing sections.

2. Accomplishment of the computer numerical model

The spatial geometrical structure, as designed and AutoCAD presented by S.C. ISPH Project Development S.A., was adopted and processed as a 2D development. The structure was than handled in AutoCAD 3D for meshing purpose and to reveal the most concerning geometrical points, as necessary to build its numerical model. The figure 2 presents a general view of the essential structural elements, meaning the transversal stepping walls with their perpendicular opened diaphragms, defining the designed spatial geometry which was already employed by Bratanovici et al., 2019, in order to produce a 1D numerical model of the Livezeni Dam accompanying fish ladder [2]. This 1D flow phenomenon model represented a meandering path divided in numerous linear sections by vertical cross sections, path perpendicular, along the spatial structure. The numerical data of the geometrical elements and all the dividing cross sections were graphically obtained in AutoCAD 3D and the general view of the entire path was generated for the 1D model by the help of HEC-RAS v.4.1 [3], a software version that allows to consider in the background (with respect to the x0y reference system) the plane image as created and stored in a .dxf extension file (see Fig. 3).

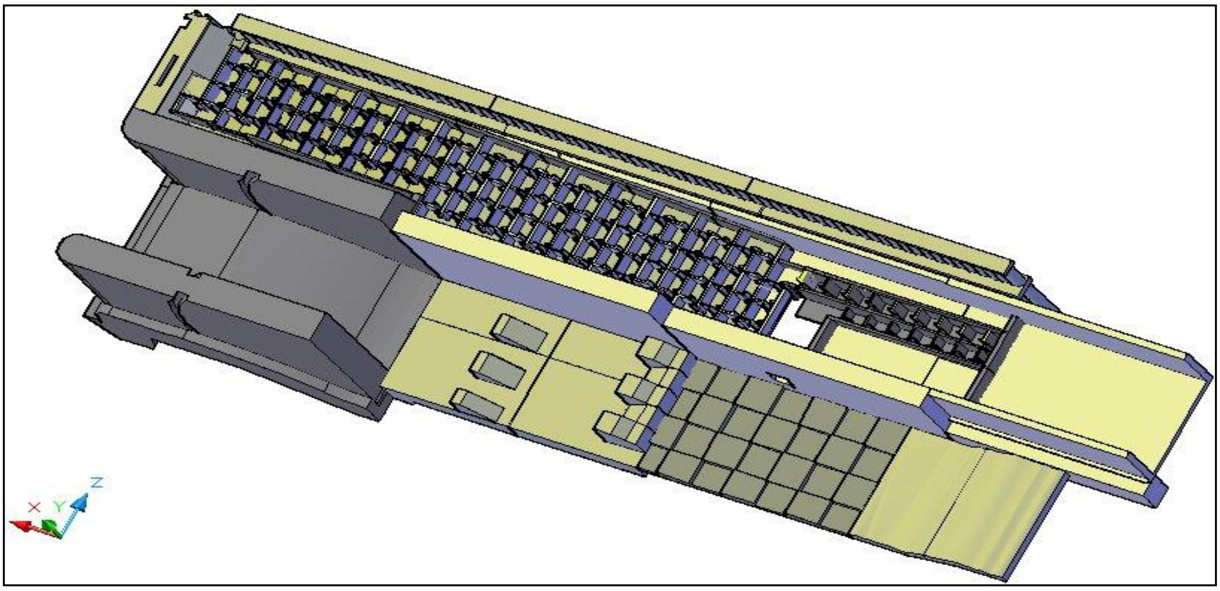

Fig. 1. General configuration of the fish concrete ladder aside of Livezeni Dam, partially showing the spillway barrage with its stilling basin and staggered blocks apron

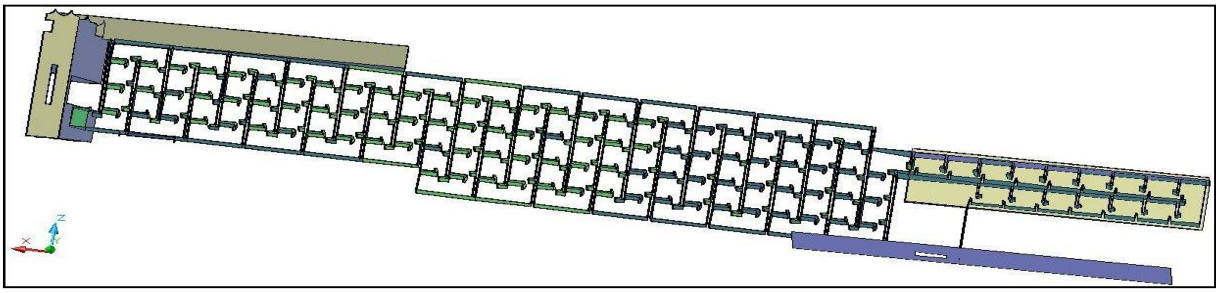

Fig. 2. General view of the three compartments fish ladder essential elements

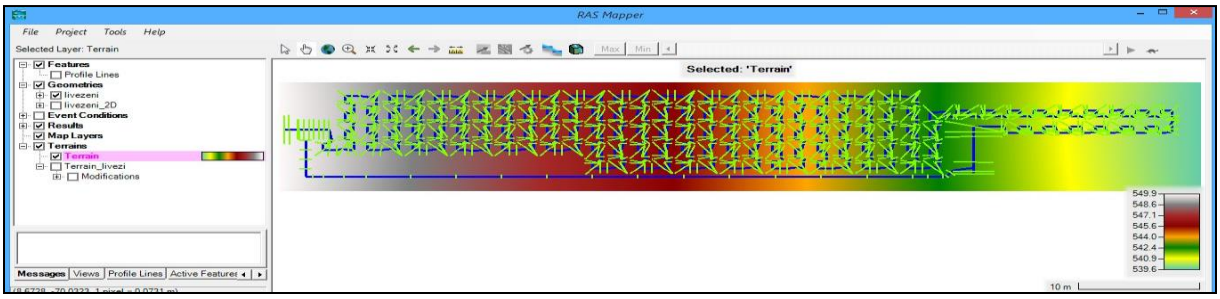

Fig. 3. Cross sections divided meandering flow path against the developed plan view of the 3D fish passage

As taking the modelling forward, at first the 1D numerical model is uploaded by HEC-RAS vers.6.1 [4] and there is generated a plane surface brought in 3D, as it is visible in the RAS Mapper graphical view of figure 3. A new 2D geometry is than generated in the updated software, starting with defining the 2D numerical model domain contour and by considering the meshing discrete dimensions, dx=dy=0.1m, and the associated points level with respect to the 0z direction. The Manning roughness coefficient was set as n=0.02.
Further on, the well-known Break Line facility is employed for all the narrowing sections and the outgoing section of the third compartment (upper view in fig.4), and specific aligning and narrowing sections areas rearranging operations are performed (as shown by detailed view in figure 4).

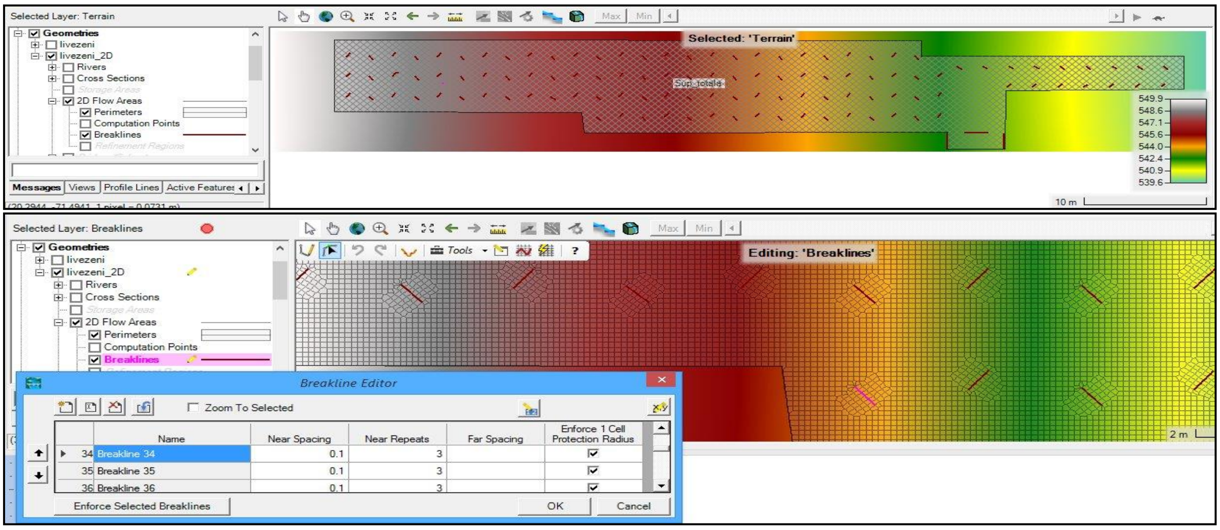

Fig. 4. Fish passage floor 3D development showing the 2D discrete meshing with the narrowing section assigned break lines (upper image) and the final rearranged and locally refined mesh of the flowing domain

The available background configuration as loaded for the 1D model [2] was also considered at the 2D model geometry generation. By maintaining the 1D path visible, each breaking line was one after the other introduced and the mesh was locally improved. In a similar way, by engaging the Modifications module, there were defined the contour and interior (transversal stepping) walls of each compartment (as in upper view of figure 5), the parting and narrowing diaphragms (straight and hook shape, figure 5) and the additional walls in the sides areas of the first two compartments (as in upper view of figure 6) or the floor connection area in the end of the third compartment (as in bottom view of figure 6).
There can be noticed in the bottom view of figure 5 the diaphragms adjusting way under a hook shape towards the narrowing gap (ladder compartments 1 and 2) in order to alter the water velocity range in the area. In the upper view of figure 6, one may notice the way of considering additional diaphragms on the sides of compartment 1, while the bottom view of figure 6 shows the way of adjusting the floor of the 3rd compartment as an improved connection with the 2nd compartment floor and to the weir staggered blocks apron. At this ladder downstream part, at the 3-2 compartments passing area as leaving the fauna comfort and accommodation pool, the position of a vertical wall was reconsidered (a previously designed wall got dropped, while another additional one was introduced). As a consequence, a significant drop in water velocity maximum values was reached also in this part of the fish passage. In the end, for the downstream passage entering part, a connection window – SA/2D Conn – was considered between the fauna comfort pool and the staggered blocks apron part of the Livezeni Dam water energy dissipater (the built numerical model covers just an apron part of ca. 1.60m wide which is downwards connected by a 1D linear segment of ca. 0.60m). The figure 7 presents the entire 2D discrete numerical model by which the ecological flow transition is simulated.

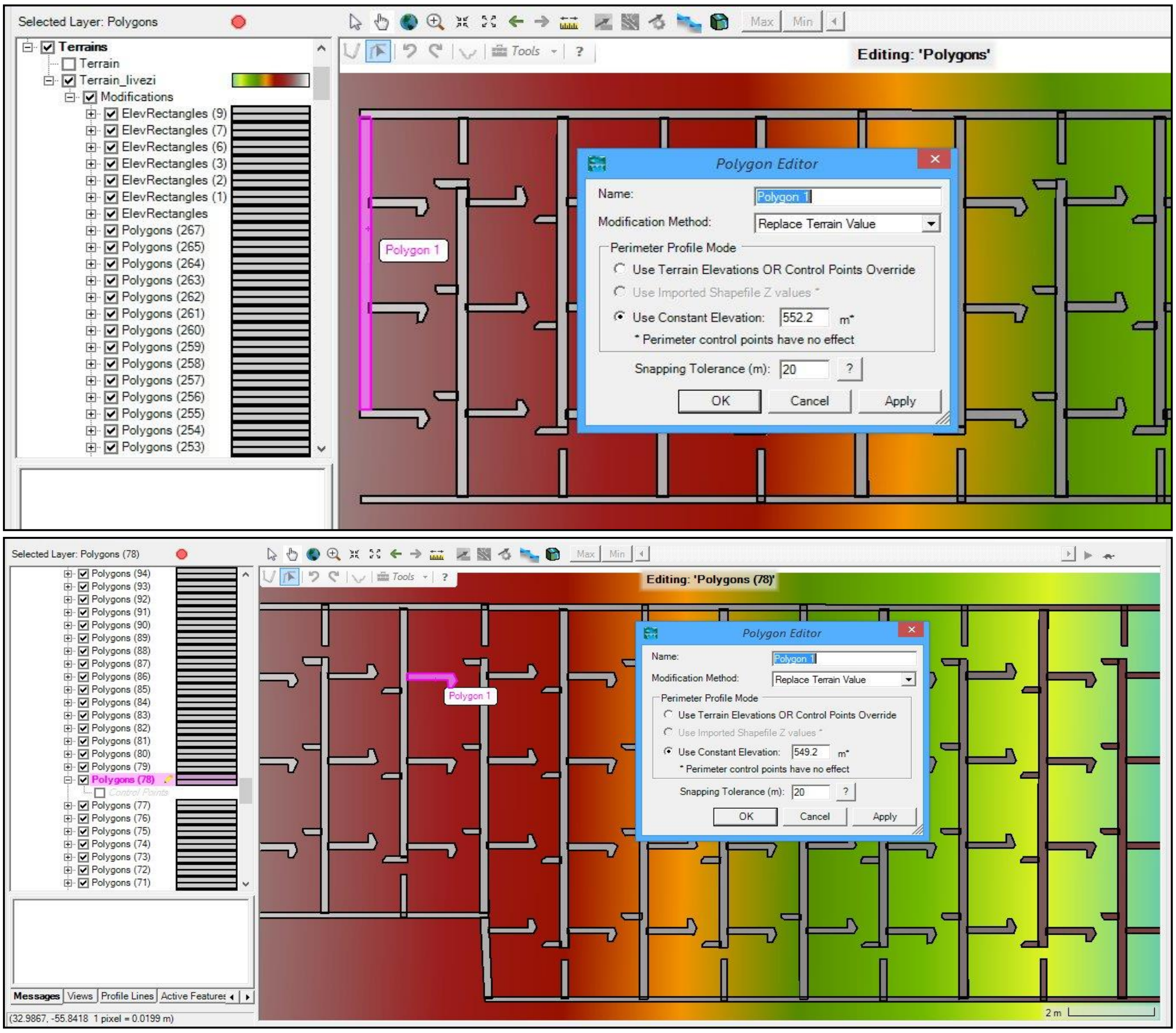

Fig. 5. Employment of Modification option for defining the contour and stepping walls (upper view), and the parting short and hook shape diaphragms (bottom view)

3. Boundary and initial conditions

As it is known for a usual study of the hydraulic phenomenon, the boundary conditions of the considered flow path are the transited discharge given as a time developed hydrograph and the total path hydrodynamic gradient. For this specific modelling, besides the transited discharge Q_{tran} = 0.45m^3/s assigned as initial entering condition to the upper BC_Sup_total_1 edge, a complementary flow Q_{compl} = 0.0935m^3/s was considered at the downward BC_S2D_2 edge at the passage connection with the energy dissipation basin (figure 8), also as an entering condition. In the same time, the hydrodynamic gradient from the 1D numerical model, as assigned to the downstream “0” cross section, is 0.0001035.

We have to mention that the complementary considered flow was estimated by the thumb rule as considering the enforced 2.70m^3/s sanitary discharge from which the 0.45m^3/s fish passage discharge was subtracted. As the total overflow dam crest opening is 38.5m, while the fish passage downstream basin connection gap is 1.60m wide, one can adopt Q_{compl} = [(2.70-0.45)/38.5]×1.60 = 0.0935m^3/s.

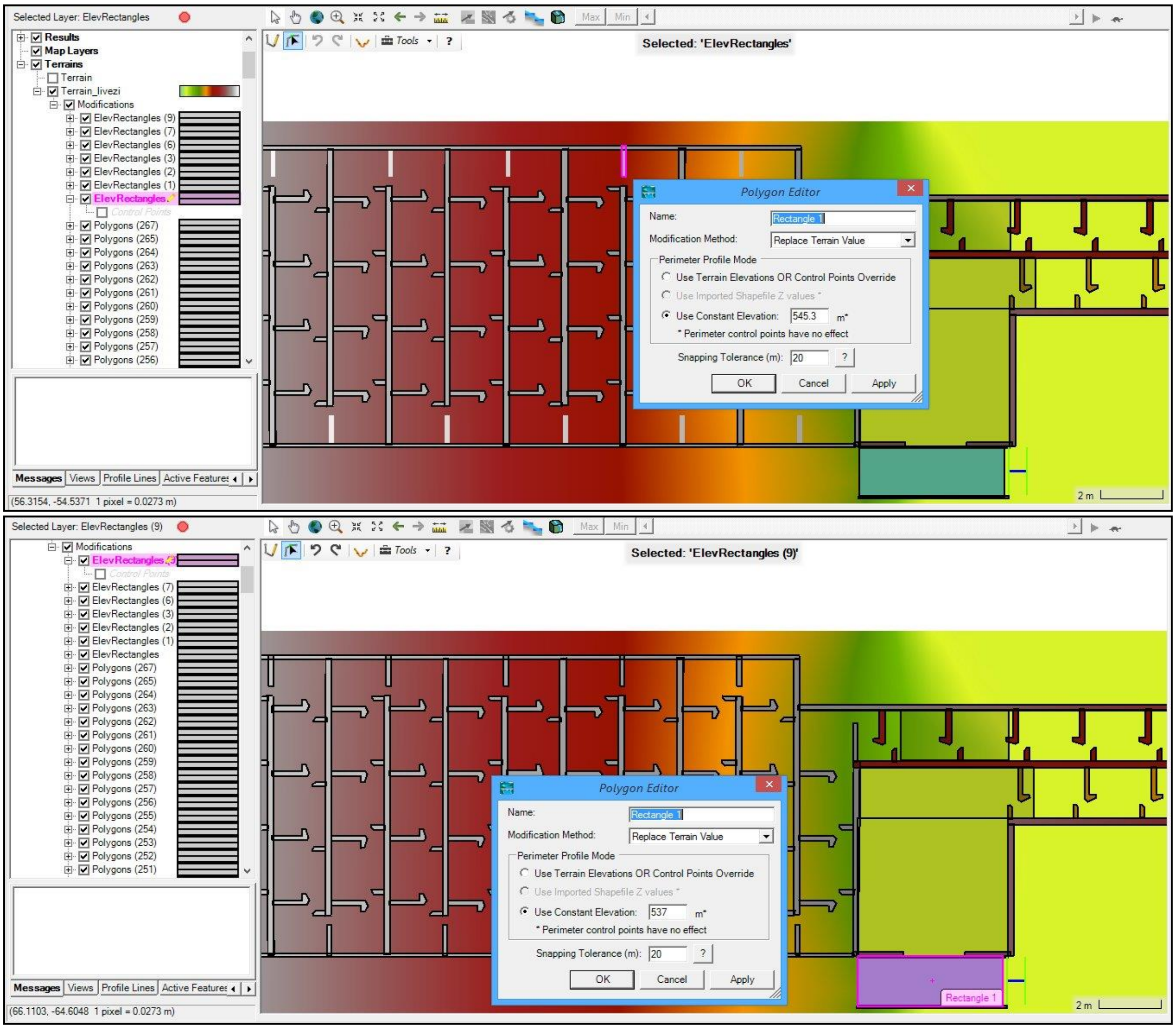

Fig. 6. Employment of Modification option for defining the sides narrowing walls in compartments 1 and 2 (upper view), and the walls and floor adjustments in compartment 3

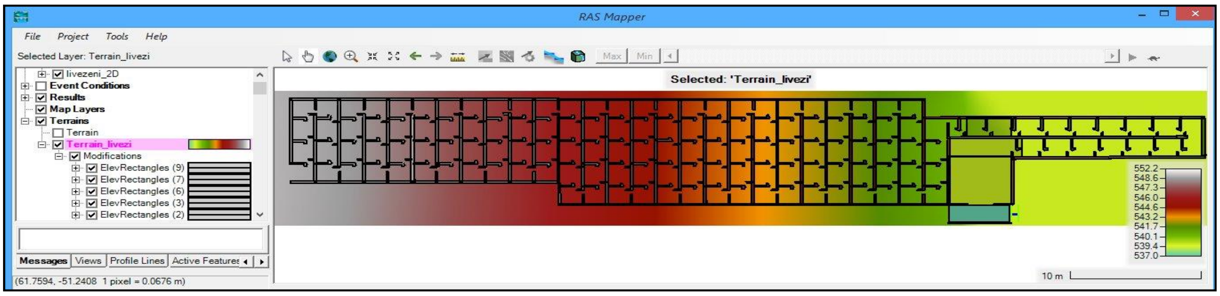

Fig. 7. General view of the developed Livezeni Dam associated fish ladder 2D discrete model

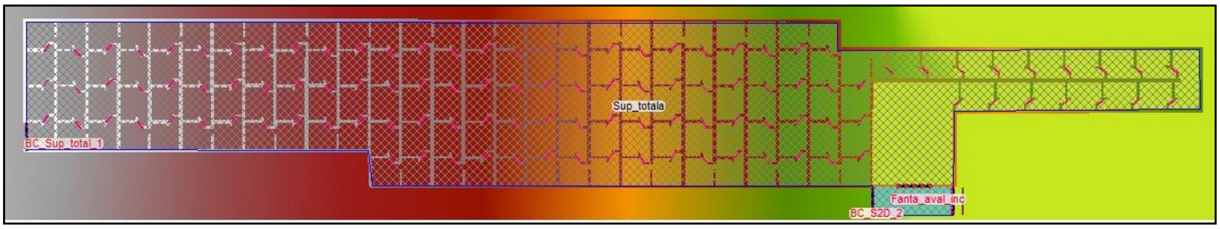

Fig. 8. The completed discrete model in RAS-Mapper module,
showing its completed geometry against the 3D (coloured gradient) floor configuration

The actual flow transition numerical simulation by the developed discrete model was performed for a specific time interval of 1h and 40 minutes (corresponding to a given significant hydrologic phenomenon, explicitly from 01:00 to 02:40 on September 1st, 2008). The running time step was set to one second, while the mapping time was considered to 30 seconds and the resulting data storing to each 5 minutes.

4. Reached results of the flow phenomenon simulation

As following the computer simulation, constant and time depending values of phenomenon parameters – water levels, flow, velocity – were revealed, both for the 2D model and for the two cross sections on the 1D model.
After performing some post-processing operations, the results were organized by specific files that can be afterwards studied by graphic visualizations and by data spreadsheets.
Specifically, the following graphically processed results are presented here as corresponding to the ending moment of the simulation period: the particles trajectories against the water level development with respect to the channel floor (fig.9), the water velocity distribution revealing also its izo-lines of a 0.25m/s value step (fig.10), and the water level longitudinal development, both along a side straight profile and along the entire meandering path by the narrowing gaps (fig.11).

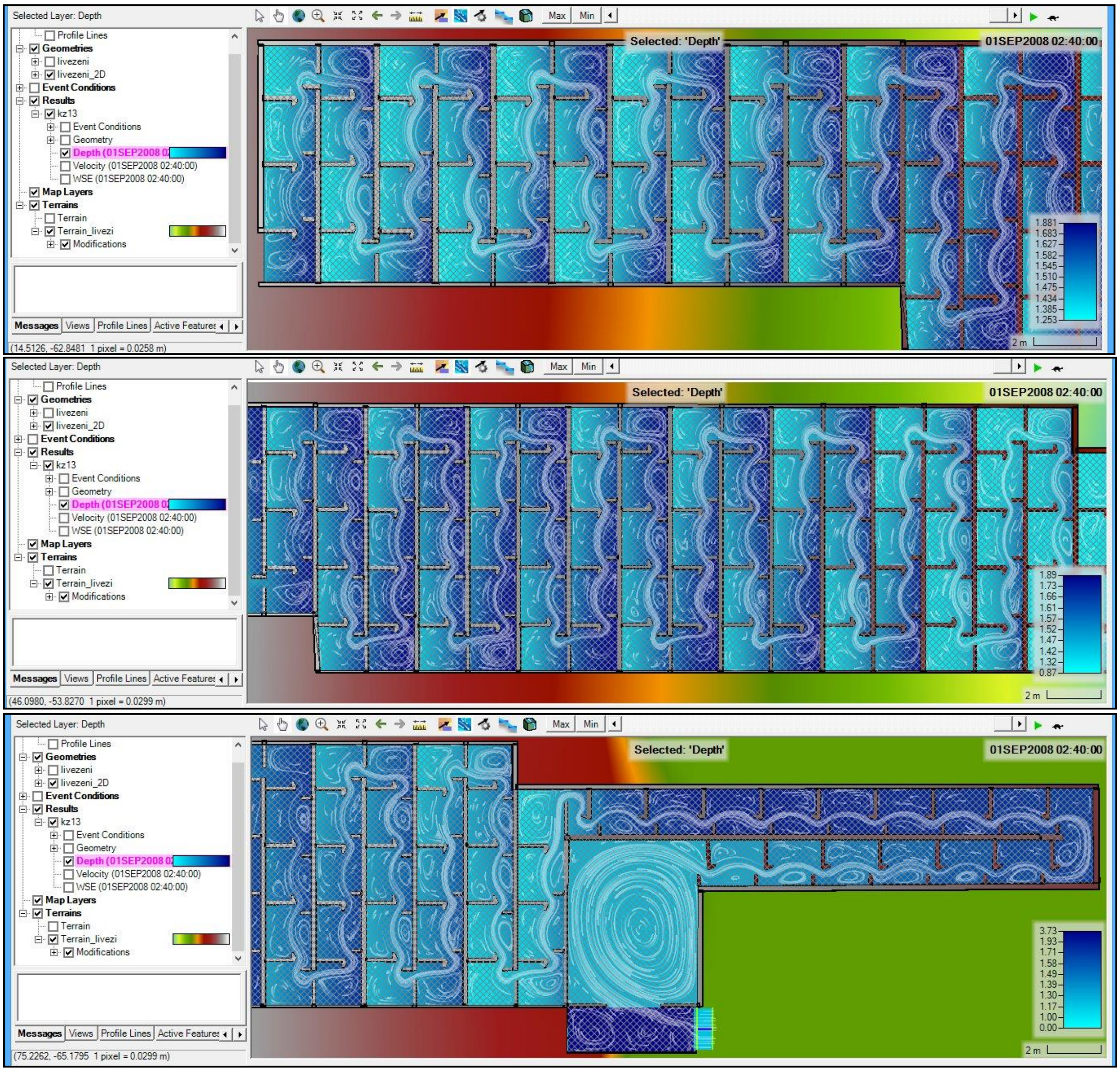

Fig. 9. Particles trajectories against water depth development by the three compartments (from up to down) of the modelled fish passage at the final moment of computer simulation time period

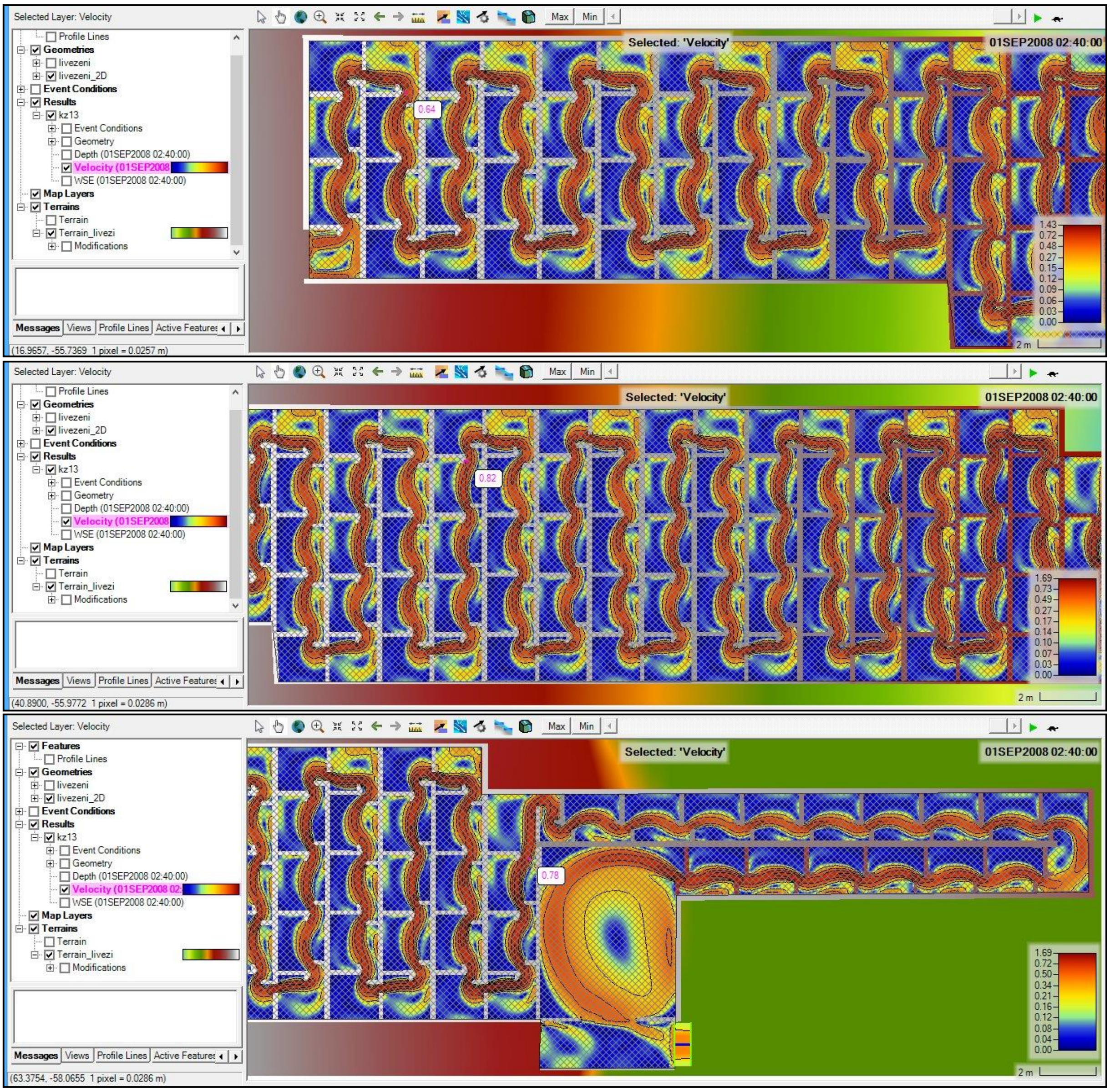

Fig. 10. Izo-velocity lines (0.25m/s value step) against the water velocity development by the three compartments (from up to down) of the modelled fish passage at the final moment of computer simulation time period

Some detailed views of the izo-velocity lines against the water velocity distribution, bringing up areas of extreme values in the three compartments, are presented by figure 12.

5. Analysis conclusions

As analysing the computer simulated water flow phenomenon by the modelled fish passage structure at Livezeni Dam, one can notice that the transition goes by a relatively slow regime along the entire meandering path. The water velocity values in the narrowing areas range generally from about 0.5 to 1.25m/s, punctually reaching a top value of 1.33m/s (fig.13). These ranging limits are to be similarly found at the narrow sections of all three compartments of the passage.
There is also mentioned that the adjustment of the hook shape at the edge of the flow transversal diaphragms on the first two modelled compartments, together with the addition of the short (90cm) narrowing diaphragms perpendicular to the sides walls (see figure 6), determine a decrease in water velocity values to about 0.5 … 0.85m/s (so better corresponding to the requesting conditions with respect to fauna) by the sides of the gaps.

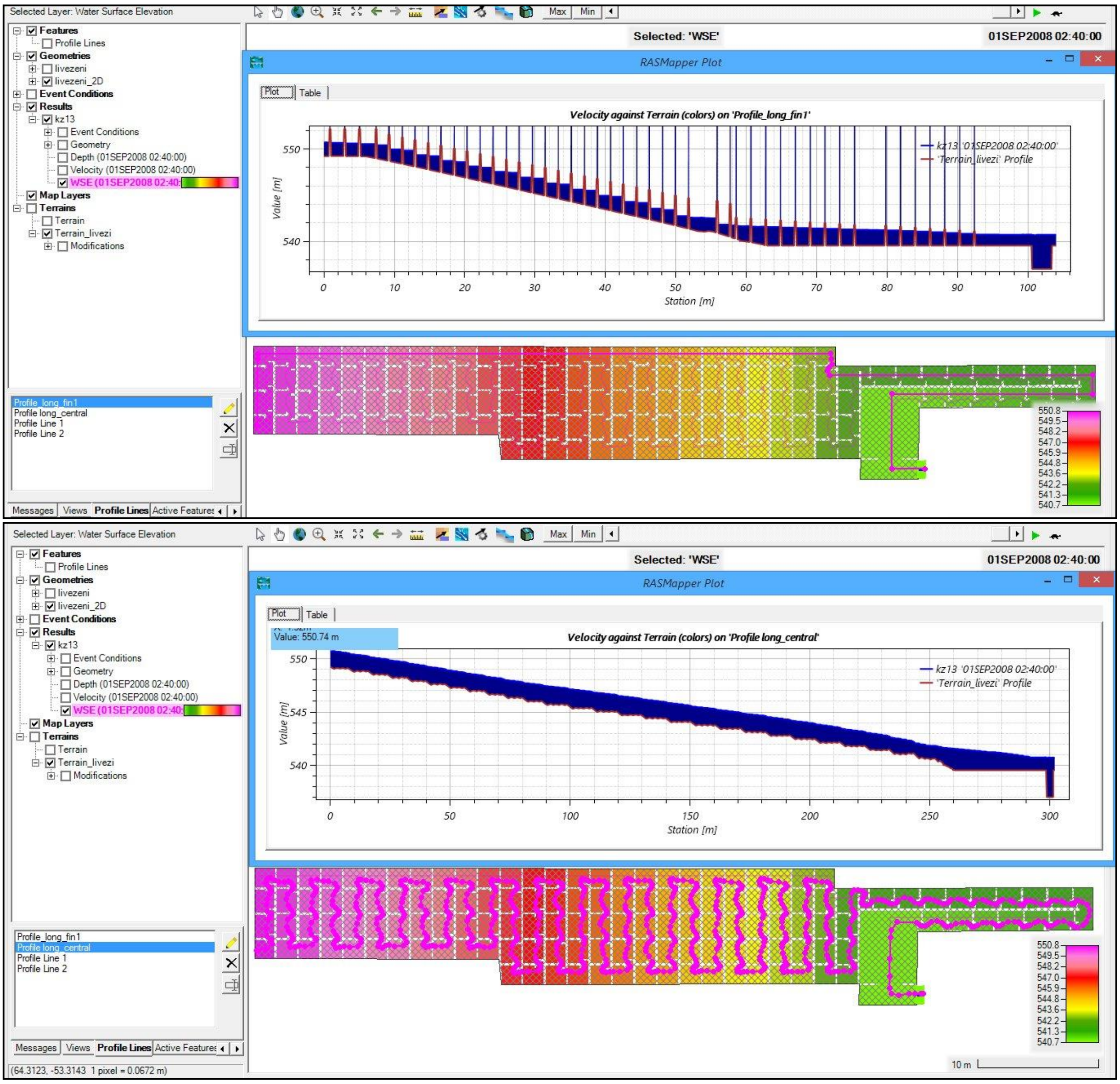

Fig. 11. Water level longitudinal development by the left side wall straight profile and along the entire meandering path by the narrowing gaps at the final moment of the computer simulation time period

In conclusion, we can estimate from the analysis of the computer modelling reached results that the considered fish passage structure configuration, adjusted after successively performed flow simulations under the ecological discharge of about 0.5435m^3/s, determines acceptable water velocity values, obeying the ranges required by nowadays regulations. Besides the necessity of the configured aquatic fauna passage as associate to Livezeni Dam, the performed study also comes in support of considering the adjoining of a micro-hydropower station to the retaining structure. As allowing it an installed discharge of about 2.40m^3/s under the given 12m gross hydraulic head, the hydropower equipment would show an installed power of about 220kW.

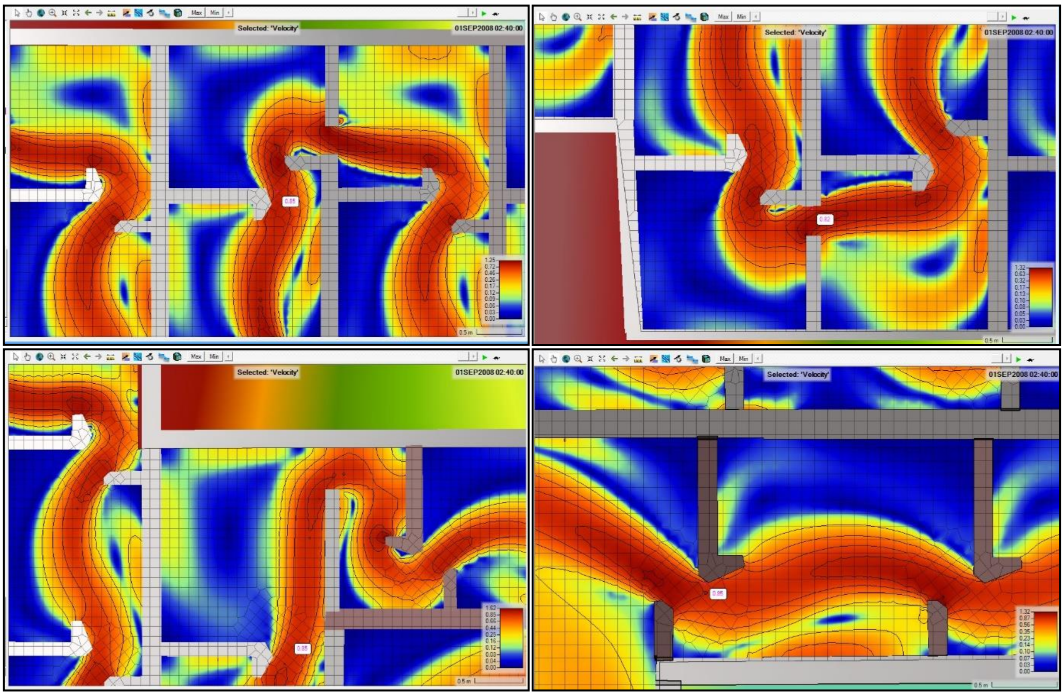

Fig. 12. Detailed views of specific areas of extreme water velocity values in the three compartments of the modelled fish passage: upper left – by the first compartment upstream (near the left side wall), upper right and lower left – by the second compartment (towards the right side wall and the left side one, respectively), lower right – by the third compartment (towards the downstream side of the apron structure)

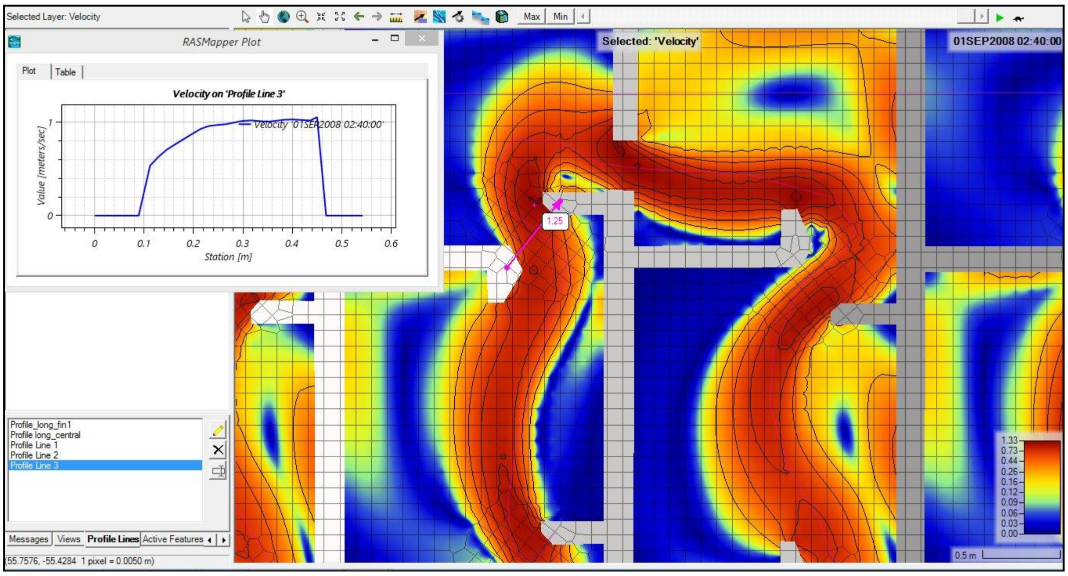

Fig. 13. Water velocity distribution detailed view at some narrowing areas in the upstream first passage compartment, near the left side wall

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