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Computer Analysis of Water Flow Transition under Existing Conditions on a River Sector in the Range of a Bridge Structure

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Abstract: *The paper presents a 2D numerical modelling of water flow transition on a sector of Strei River in the range of the DN7 national driveway bridge at km.376+818, outside the built-up area of Deva Town (upstream of Simeria), Romania, in case of a special highwaters phenomenon. The considered synthetical hydrograph follows an exceptional hydrologic event that occurred in the last days of April 2000 on the studied river sector. The numerical simulation looks to estimate (reconstruct) the water levels evolution and velocity distributions under the bridge and on the influenced upstream/downstream river stretches.*

Keywords: *River flow, highwaters flow, bridge hydraulics, numerical model.*

1. General considerations

The presented numerical model of Strei River sector in the range of the DN7 bridge at km.376+818, vicinity of the built-up area of Deva Town (Simeria), Romania, considers a formerly developed technical expertise [1] and feasibility study [2] upon the analysed site regarding the state and reconstruction of a river bottom step and the time affected riverbed. The Strei River crossing by the national driveway DN7 is accomplished by a concrete bridge of four gaps, the central two in the riverbed limit and the side ones towards the bordering floodplains (Figure 1).

Fig. 1. Driveway bridge on DN7 at km.376+818 Strei River
left - upstream view, right - downstream view

The two middle spans have an opening of about 28m between the abutment piers and showing a foundation spacing of about 24m, while the sides spans presenting a 19m abutments opening and a 17m foundations spacing. The bridge leans against the two side abutments, the total span being supported by the three intermediate abutment piers. The side abutments have a geometry upstream / downstream extended by cone quarters. The abutment piers have a thickness of about 1.60m, a length of 8.00m and an above foundation height of 2.60m (foundation block top level at 93.90mSL, to abutment level at 96.50mSL). The actual ground surface configuration under the bridge and for its upstream / downstream river stretches (figure 2) was supplied according to topographic measurements performed after the highwaters event that occurred on Strei receiving basin in December 2003.
The following data was required for the hydraulic approaches that looked to establish the overall flow transition– water levels and velocities time development – on the bridge river sector: maximum flow values of specific overrunning probabilities, the synthetic highwaters hydrograph, streambed and river banks roughness coefficients, and flow hydrodynamic gradient (at high waters especially).

The maximum flow values on the analysed sector of Strei River, as supplied by the Mureș Regional Water Branch of Romanian Waters National Administration, are: $Q_{5\%}$ = 480 m^3/s, $Q_{2\%}$ = 590 m^3/s, $Q_{1\%}$ = 680 m^3/s and $Q_{0,1\%}$ = 695 m^3/s. As about the development of the highwaters hydrograph, its shape was provided as associated to the 1% overrunning probability water flow. Regarding the hydrodynamic gradient, it was estimated as 0.62‰ associated to usual low levels flow and as 2.4‰ correlated to high water levels flow. The roughness coefficient corresponding to the riverbed was estimated at about 0.025…0.040 while corresponding to the river banks about 0.040….0.060.

Fig. 2. Site view of the DN7 bridge over Strei River as supplied by topographical measurements

The study of the flow regime under the existing geometry configuration was performed by developing a numerical simulation of the river sector discharging capacity. The river geometry modelling considers the specific upstream/downstream sector of about 447 m in length. The numerical simulation was developed by the help of HEC-RAS 5.0.6 [3]. A specific data base reflecting the terrain configuration (as shown by the Stereo 70 topographic measurements containing 7848 points) was created to cover the regular flow path and neighbouring floodplains. Six cross views (two on the upstream side of the bridge, PT4 and PT2, and four along its downstream side, PT1, PT3, PT6 and PT5, respectively) were organized in order to better point out the geometrical configuration of Strei River streambed and floodplains.

2. Development of the 2D numerical model

A "satellite" graphics given by Earth Explorer is usually employed as a common approach for the graphic accomplishment of a 3D ground configuration. Nicoară et.al. [4] follows a facile graphic processing of given (measured) topographic data. There is engaged a 2D graphic interpolation method able to generate a 3D surface in a shape type file (extension .shx) – the topography data base for the analysed surface is comprised from 7848 measurement points of coordinates x and y, and level z (figure 3.left). The surface uploaded by ArcMAP 9.3 [5] was meshed by discrete triangulated elements resulting a digitized shape in a 3D space, type **T**riangulated **I**rregular **N**etwork (TIN, figure 3.right). The created shape was then converted into an accessible Digital

Terrain Model file in order to be recognisable by RAS Mapper graphic module in HEC-RAS 5.0.6 [6,7]. The geographic coordinates system was considered and then the final converted ground configuration in an .FLT extension file was uploaded in RAS Mapper (figure 4). Specific information and approaching sequential procedure with respect to geometrical data conversion can be obtained from the mentioned documentation [4,7].

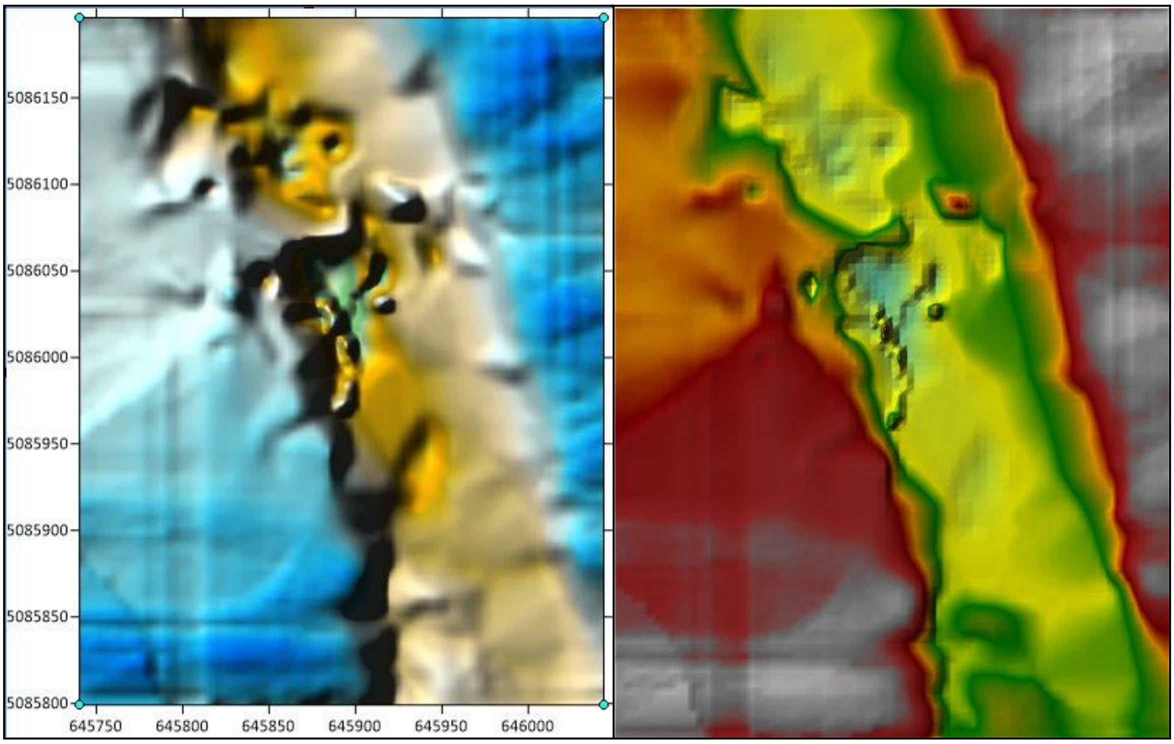

Fig. 3. Graphic view of the analysed site on the range of Strei River crossing bridge:
left - coloured processed 3D surface of topographic measurements, right - processed surface

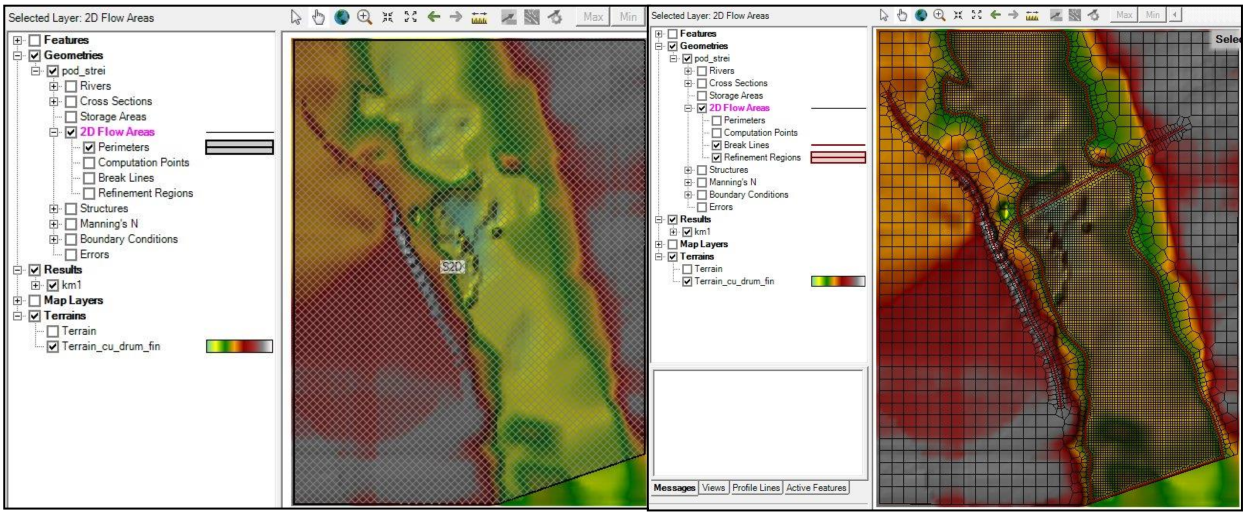

Fig. 4. Processed 3D analysed site on the range of Strei River crossing bridge:
left - general meshing, right - enhanced in the riverbed area

There can be appreciated that the 3D representation "satellite" model gives an adequate, quite realistic, digitized ground configuration (excepting the left bank roads outline that required a significant further improving alteration following updated procedures for flood protection embankments [8]). Even if the numerical geometry model is constructed on a relatively reduced number of topographical measured points – 7848, it still reasonably fulfils most of the natural terrain details as a 3D surface shape.

Accordingly, the digitized terrain model (figure 3.right) of the cut-out sector from Strei River covering the specific driveway bridge was considered in the 2D analysis domain of HEC-RAS 5.0.6 under the name "pod_strei". The 2D Flow Areas layer is accessed in the explorer type window in order to draw the 2D analysis domain contour (labelled S2D in figure 4.left). There was considered a general mesh of 10m × 10m grid size for which the associated points and their accompanying properties tables were generated (Generate Computations Points, Compute Property Points) and saved. A grid enhancing step was performed for the river-course area to engage a 2m×2m grid size (figure 4.right).

A grid break line was defined on the bridge axes direction in order to even more enhance the meshing of this important zone to 1.5m × 1.5m (figure 5) by considering additional points. The grid break line helps also to align the neighbouring grid cells on its defined direction, but even more important it allows to define a joining structure. So, by employing the SA/2D Area Conn facility in the main menu (Geometries), there was inserted a specific structure (overlaying with the defined grid break line) that connects the two adjoining zones of the numerical model.

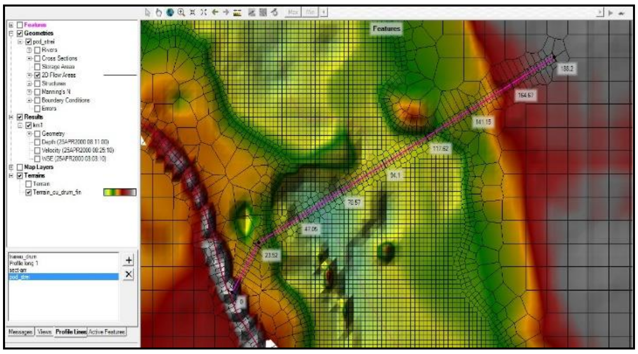

Fig. 5. Site detailed view in the immediate bridge area

There was defined the bridge geometric shape with its accompanying hydraulic conditions (figure 6).

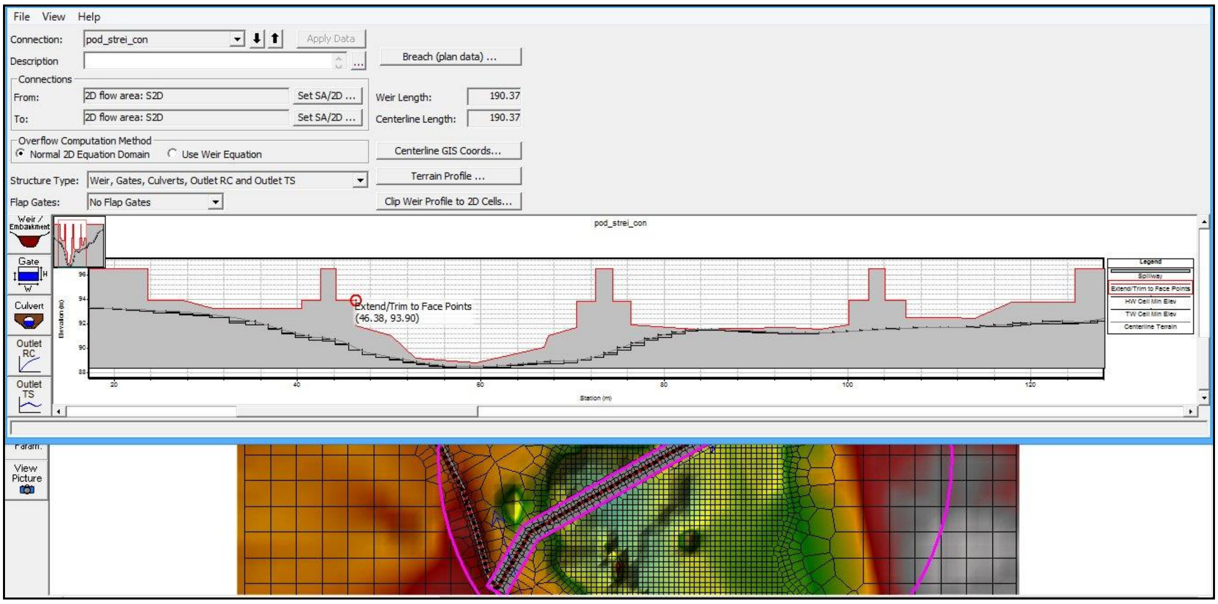

Fig. 6. Definition of the geometric and hydraulic conditions of the bridge axis river cross section

As about the 2D numerical model required boundary / initial conditions, they were defined in the Geometric Data main menu by the help of BC Line facility (SA/2D Area BC Lines option, figure 7). Two border lines were considered for this specific 2D domain, one on the river upstream entering model edge (BC_S2D_11) to which the highwaters hydrograph is to be assigned, and a second one upon the corresponding downstream edge (BC_S2D_22) which is to receive the hydrodynamic gradient of the water surface. Explicitly, the considered highwaters hydrograph on the specific site of Strei River corresponds to the maximum water flow $Q_{0,1\%}$= 695 m^3/s and the accompanying energy gradient 0.0024 (value by which the software will conclude the flow time distribution), as assigned to BC_S2D_11 edge line (figure 7). A hydrodynamic gradient value of 0.0024 was assigned to the downstream BC_S2D_22 line.

The actual numerical simulation of the flow transition was performed over a given time period that corresponds to a significant hydrological event of highwaters, meaning from 00:00 on April 24th to 16:00 on April 25th, 2000 (even if the entire phenomenon went on decreasing for another four days).

The analysis was set to run with a time step of 0.2 seconds and a mapping time step of 10 seconds, while the results were to be registered at each 10 minutes.

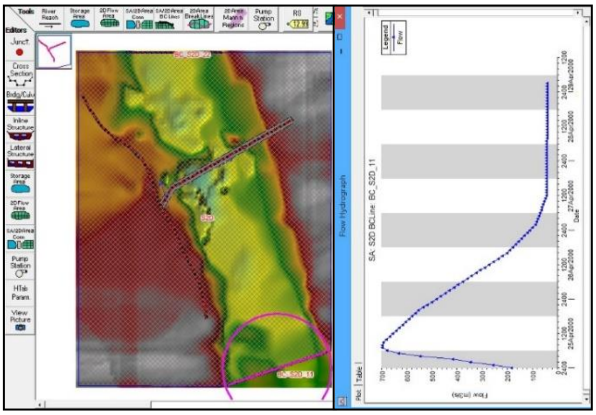

Fig. 7. Upstream/downstream boundary conditions assignment on the analysis domain and the upstream attached hydrograph development over the considered period (00:00 24th to 03:00 29th, April 2000)

3. Significant results of the numerical simulation

The following steady or time dependant water course parameters were reached in each 2D model cell by running the numerical simulation: surface levels, flows and velocities. Following certain graphic post-processing operations, the numerical results were stored in distinct files that can be afterwards visualized with respect to any required cell or along paths as defined by the user, by engaging the RAS Mapper options [7].
Several graphic depictions are further on selected for significant preestablished moments (figure 8), specifically when the water flow successively reaches the values approximately corresponding to the start moment (Q_{start} = 180m^3/s) and the mentioned standardised overrunning probabilities (i.e. $Q_{5\%}$ = 490 m^3/s; $Q_{2\%}$ = 590 m^3/s; $Q_{1\%}$ = 680 m^3/s and $Q_{0.1\%}$ = 695 m^3/s). There were also selected some noteworthy features, such as water surface elevation, particle tracking visualization or water surface longitudinal profile configuration.
As it is known, the water flow transition by the analysed river sector is influenced by the bridge structure, firstly meaning a water elevation increase. Specifically, the water surface elevations shown in the significant river cross sections – upstream model entering border, immediately upstream and downstream of the bridge structure and downstream model outgoing border – at the five specified moments along the simulated time periods are presented by the following table no.1 (as illustrated by figure 8 longitudinal development).

Table 1: Significant water levels along the modelled river sector

station / moment	Water Surface Elevation [mSL]			
	model entering	upstream bridge	downstream bridge (drop, cm)	model outgoing
00:10 (180m^3/s)	93.656	93.654	93.648 (6)	92.296
03:40 (498.6m^3/s)	94.587	94.562	94.533 (29)	92.951
04:30 (585.7m^3/s)	94.786	94.753	94.716 (37)	93.076
06:10 (680m^3/s)	94.980	94.946	94.910 (36)	93.231
07:40 (695m^3/s)	95.008	94.977	94.936 (41)	93.243

Figure 9 shows the particles tracking detailed visualization overlaid to water depth image for the immediate bridge area at the specific moment of maximum 695m^3/s flow, 07:40 on April 25th, 2000, while the next figure 10 brings as trajectories background the velocities distribution for the same river stretch aside with velocity longitudinal development at the mentioned significant time moment.

The last figure indicates also the bridge structure influence with respect to the water level rise in the immediate upstream cross section and consequently the increased water velocity that reach the maximum value of about 7.10 m/s in the immediate downstream area.

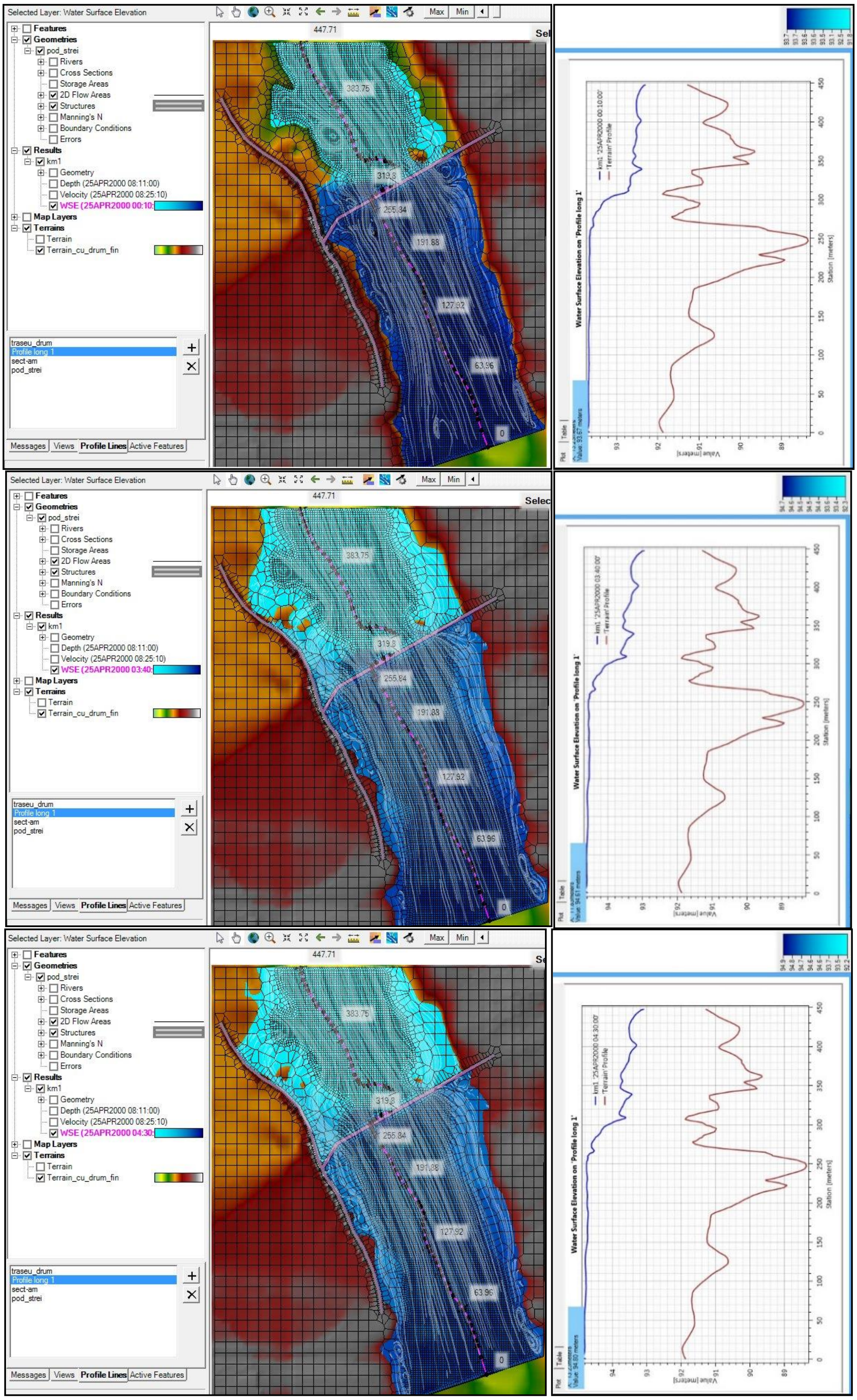

Fig. 8.a. Particles trajectories overlaid to water surface elevation development and thalweg longitudinal view of water surface at five specifically defined moments on April 25th: 00:10 (corresponding to the start flow value 180m³/s), 03:40 (498.62m³/s reached flow), 04:30 (585.68m³/s)

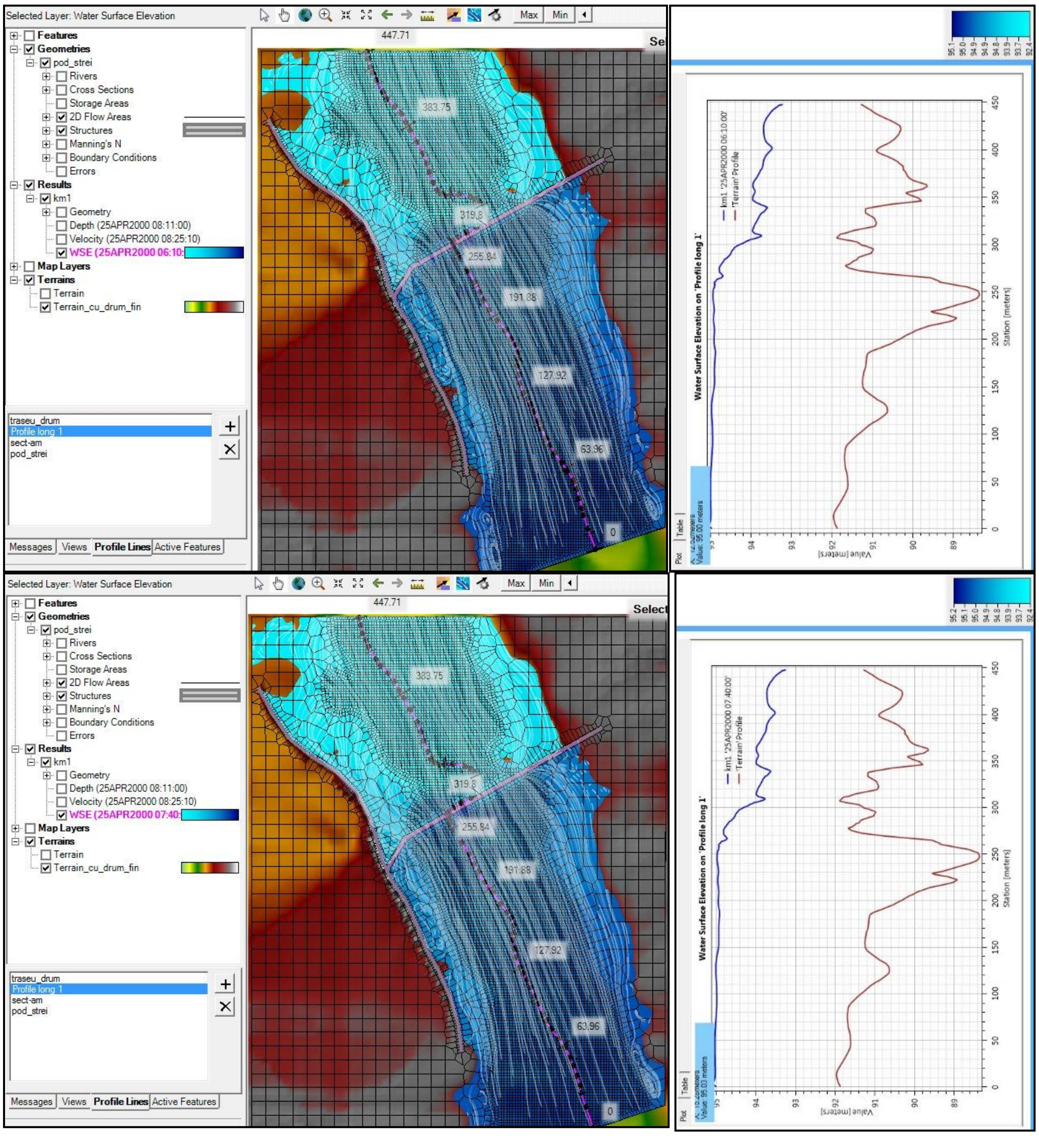

Fig. 8.b. idem previous: 06:10 (679.96m³/s) and 07:40 (695.01m³/s)

4. Conclusions

Based on the field observations and supplied topographical measurements, the performed hydraulic numerical modelling of Strei River sector in the range of the bridge at km.376+818 on DN7 driveway brings us to the following main conclusions with respect to the streambed state and processes:

- The bridge area streambed, both towards upstream and downstream, used to show at that time as silted on the central-right part, fact that pushed the main stream flow mostly under the central-left span where it generated important scourings, especially heightened against upstream of the central abutment pier foundation (thalweg level with about 5.46m below foundation top level and ground level near foundation block with only about 1.96m above thalweg);
- Due to alluvia deposits developed in the bridge downstream area, the streambed got an altered plan geometry, as the numerical model accordingly considered. Consequently, the flow stream was not anymore aiming towards the central span of the railway bridge following at about 300m downstream (not covered by the present model) but was tending instead against the left bank access ramp of this second bridge;
- The major river course in the analysed area proves to have the discharge capacity even under the maximum forecasted flow of 1‰ overrunning probability, $Q_{0,1\%}$ = 695 m³/s.

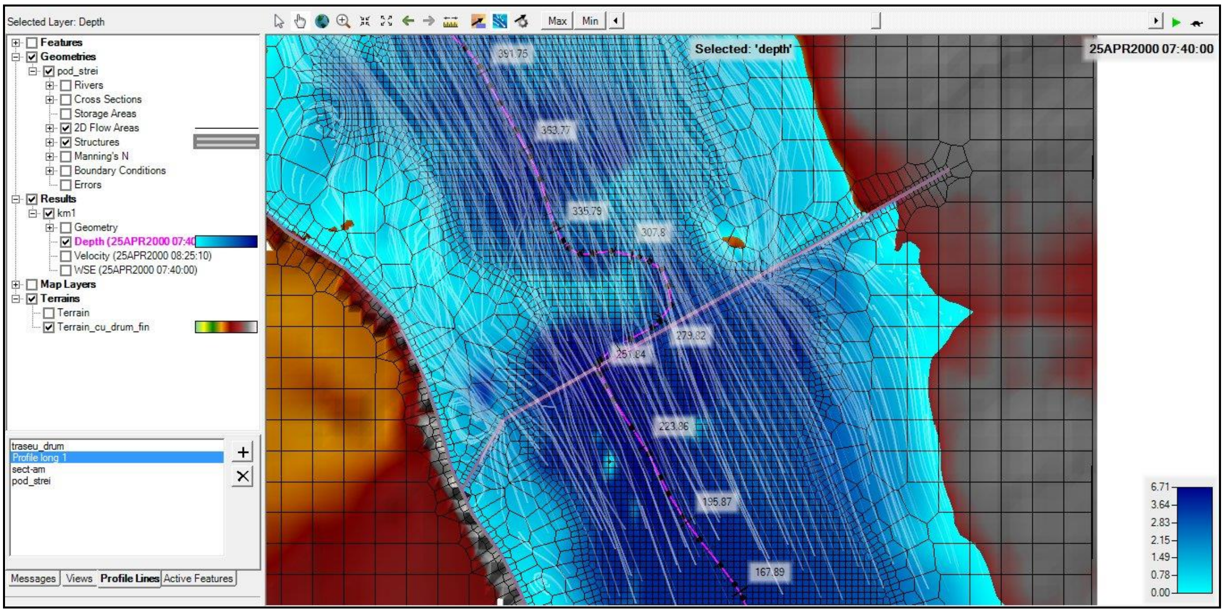

Fig. 9. Detailed particle tracking visualization overlaid to water depth image in the bridge area at 07:40 on April 25th, 2000, of maximum 695.01m³/s flow

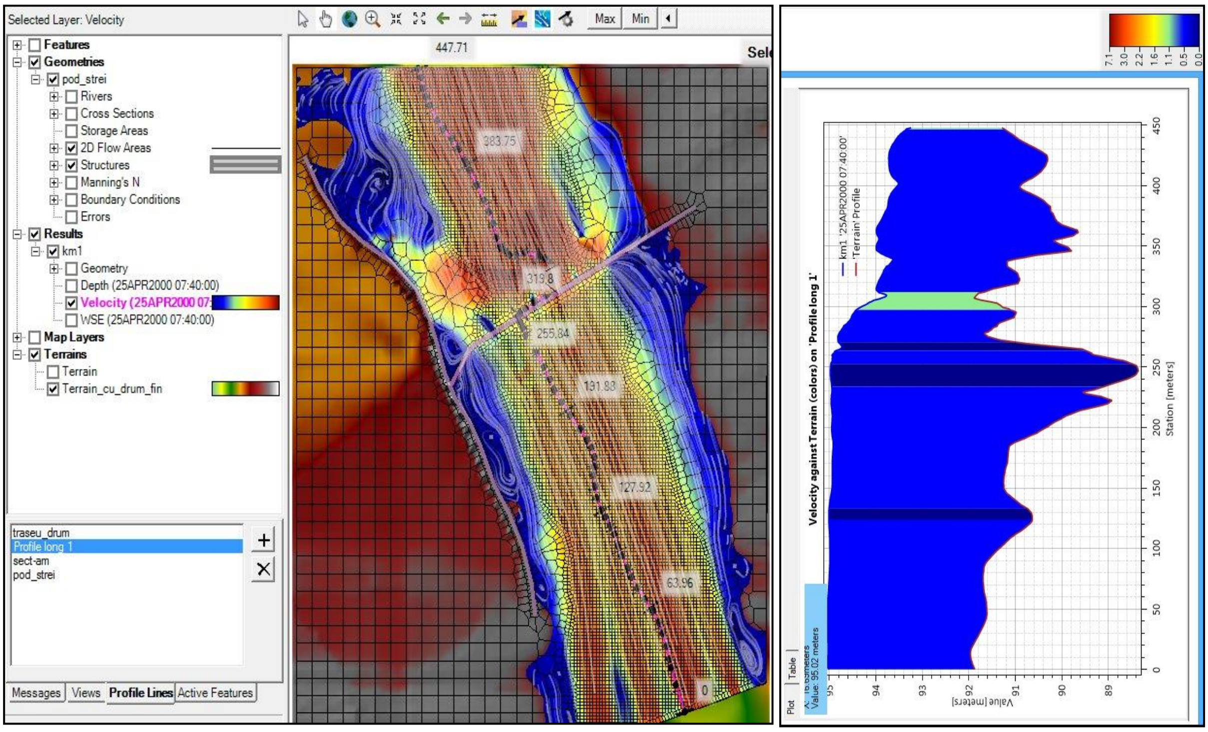

Fig. 10. Detailed particle tracking visualization overlaid to water velocities image in the bridge area and thalweg longitudinal view of water velocity development at 07:40 on April 25th, 2000, of maximum 695.01m³/s flow

Further on, in order to achieve the general streambed balance in the analysed river sector under the reasonable requirement of improving the under-bridge water discharge capacity, one can suggest some measures for plan shape correction and riverbed processes diminishing:

- Accomplishment of a bottom step downstream side of the bridge that would re-silt the central-left span and would stop the general scourings under the crossing structure;
- Accomplishment of side-bank protections on the resulting bridge - bottom step stretch and also for a length of about 50 to 100m on both directions, downstream of the bottom step and upstream of the bridge;

● Remove of the worthless and abandoned concrete blocks from the riverbed in the bridge area, which would improve the flow pattern;
● Upstream and downstream streambed calibration by removing the developed alluvia deposits, which beside a flow pattern improvement would also help to point the main stream flow towards the central part of the downstream railway bridge;
● Accomplishment of at least two river groins about the left bank downstream of the suggested bottom step, which would ensure the stream flow pointing towards the central part of the railway bridge and so would remove the threat upon the bridge left access ramp.

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