Reconstruction of River-Course Processes by a 1D Numerical Modelling

Assist.prof.dr.eng. **Alina-Ioana POPESCU-BUȘAN [1]**

[1] POLITEHNICA University Timişoara, alina.popescu-busan@upt.ro

Abstract: *The paper presents a 1D numerical approach aiming to analyse the river-course processes development as emphasised by the river left side upper bed scouring on Timiș River, West of Romania, downstream of a crossing road-bridge. The quasi-unsteady flowing regime is modelled over a hydrologically significant time interval during the spring season of 2005.*
The analysis looks to reconstruct the side scouring occurrence and progress as a result of river-bed sliding instability under given special conditions produced by accidental high-waters. By employing the HEC-RAS software package, the numerical simulation considers the river sector morphological conditions determined by the crossing structure as transiting the liquid hydrograph and the corresponding sediment transport.

Keywords: *River flow, bridge hydraulics, highwaters flow, sediment transport, river-bed process, numerical model.*

1. General situation

The numerical model covers a sector of about 6484 m length from Timiș River (figure 1) on the south edge of Șag Village in Timiș County, West of Romania. As the influence area of the concrete crossing bridge on National Road 59, the river sector is to transport the non-permanent flow under a quasi-unsteady regime. The discrete numerical modelling was studied by the help of HEC-RAS 5.0.6 specialized software [1].

Fig. 1. Aerial view (Google Maps) of studied Timiș River sector south bordering the Șag Village (flowing right to left)

There was considered a topographical data base as produced for the river sector area in 2005 [2], shaping the general plan view with 22 measured and 4 linear interpolated river cross-profiles. The river cross-profiles point out the geometrical configuration of the main river-bed and its sides flood plains.
The water surface level development in time, the flowing velocity regime and the sediment transport phenomenon on the considered river sector are to be reconstruct as corresponding to a given maximum flow of 1% overrunning probability developed by a specific high waters hydrograph. The roughness coefficients for the river-bed and flood plains area, the river sector hydro-dynamic gradient and the flow – level curve (as supplied for a downstream measured cross-section) were also engaged.

2. Numerical modelling of the liquid and sediment transport under the quasi-unsteady regime

The 1D numerical model was created by dividing the river sector in 25 straight segments as defined by the 22+4 cross-profiles [3]. Besides the ground geometry, the model considers an inherent bridge type structure. The actual model initiation was performed by following the common operations in HEC-RAS 4.1 [4,5] (figure 2).

The graphic image in figure 3-left presents the geometric characteristics of the inherent bridge structure (seen from the left bank to the right one) as modelling the concrete road bridge of six gaps (see picture presented by figure 3-right), two of them covering the thalweg river-bed, one connecting towards the right abutment pier, and three covering the upper bed towards the left abutment. As taken after the special hydrological events of the spring of 2005, the picture shows also the altered scouring on the left side upper bed.

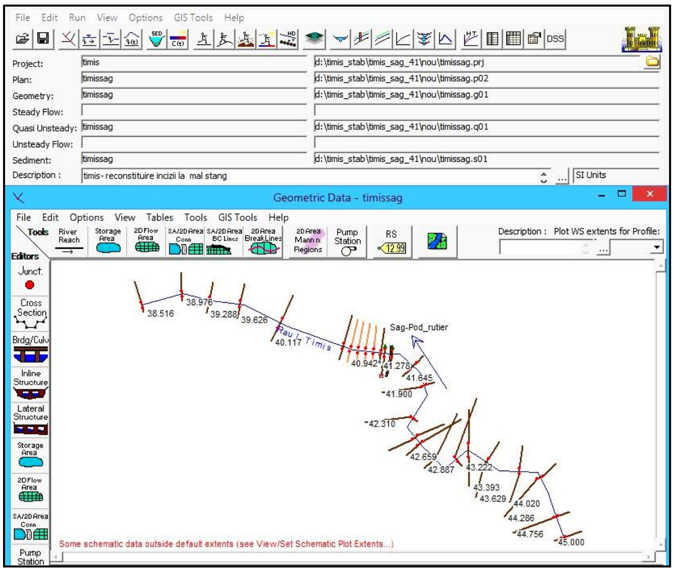

Fig. 2. Path view of the Timiş River sector 1D model also indicating the cross-profiles

Since sediments physical data are uncertain, the sediment transport modelling is a difficult problem. In the same time, one should be aware that the transport theory is largely empirical and so very sensitive to a significant range of physical variables considered as model parameters, especially hard to measure or estimate.

Among its several resources, HEC-RAS 5.0.6 also comprises specific modelling capabilities regarding sediment transport as ground (bed) movable boundary (surface), successively altering the cross sections geometry as a response to sediments dynamics [6]. The software can correspondingly simulate banks deteriorating processes and resulting alluvia transport.

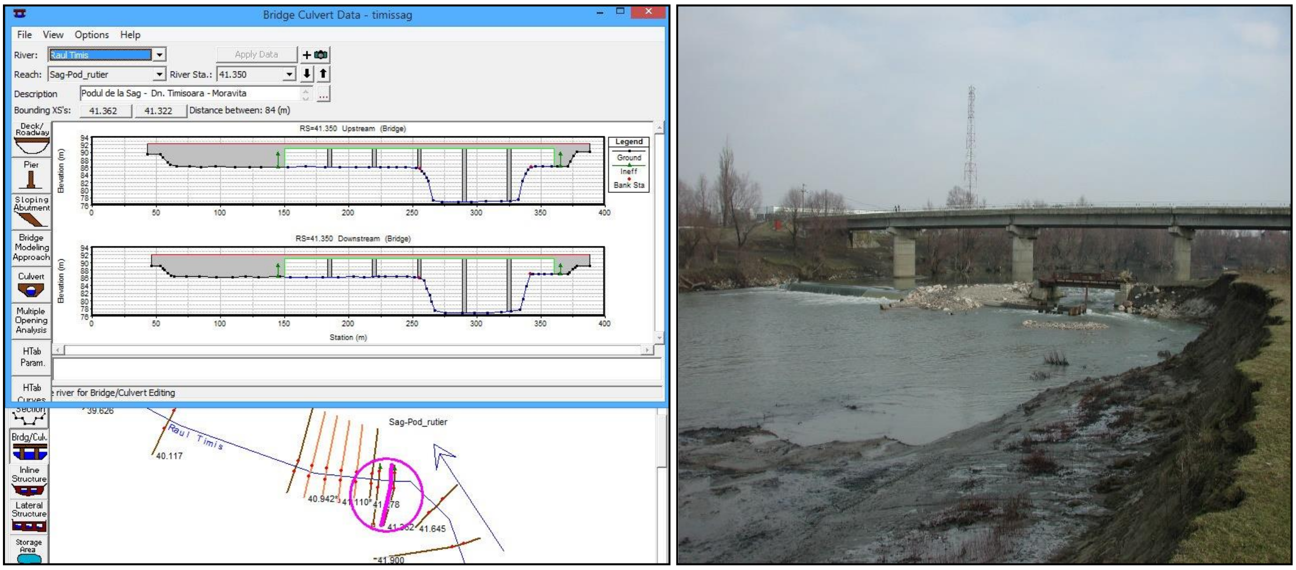

Fig. 3-left Geometrical and hydraulic characteristics of the bridge structure; **-right** Downstream view of the modelled concrete road bridge presenting the general scouring of the left side upper bed as produced by 2005 spring hydrological events

The sediment transport hydraulics is combined with the unsteady (transitory) or quasi-unsteady flow hydraulics. The quasi-unsteady flow model simplifies the phenomenon hydro-dynamics by considering the continuous hydrograph as modelled by a series of discrete constant flow profiles. For each given flow constant value, the software performs the transport calculations along the specific time step. Specifically, for each constant flow interval HEC-RAS 5.0.6 establishes the computational increments that model the hydraulic and sediment transport phenomenon development. So, the river-bed geometrical configuration and flow hydraulics are continuously updated along the simulation period.

Thus, by following the quasi-unsteady approach, figure 4 (left) shows the considered flow hydrograph [2] as altered in a series of constant flow value steps, the associated time interval for each step (Flow Duration) being adopted in this case as 24 hours. Further on, the adopted Computation Increment was one hour along all time intervals.

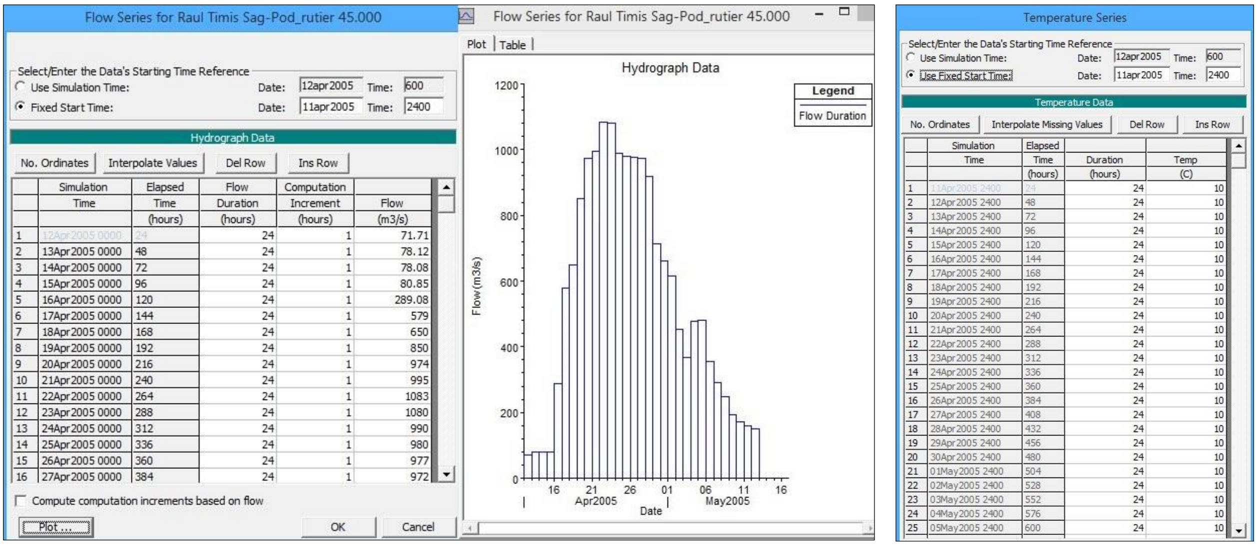

Fig. 4. Altered flow hydrograph covering the total simulation period, April 12th to May 12th, 2005, and the as adopted corresponding air temperature development

The graphical image in figure 4 also indicates the way of advancing through the specific facilities available for flow hydrograph editing, together with the accompanying daily temperature editing (even of no eloquent effect in this case).
As common procedure, the quasi-unsteady model in HEC-RAS 5.0.6 requires three specific files, one covering the flow data (constant or unsteady), one storing the geometry data and the third one bonding the first two. The constant or unsteady alluvia (sediments) flow analysis brings in a fourth distinct data file. The figure 5 specifies data regarding sediments and specific geometry elements. Some of the required sediment parameters are to be defined for each of the numerical model cross sections. The following options were considered for the sediments transport analysis: Laursen-Copeland model for the transport function, Active Layer method as the river-bed mixing simulation and the Rubey model as the fall velocity computing method.
There are three facilities with the sediment data edit menu (figure 5), the first two – Initial Conditions and Transport Parameters, Boundary Conditions – which need to be considered for any sediment transport analysis, and a third one – USDA-ARS Bank Stability and Erosion Model (BSTEM) – which is to be accessed in case of river-bed or banks failure and transport of produced material [7].
As given the site characteristics, the movable river-bed layers were defined of a single gradation feature (identified as Sand) by specifying the material granulometry (figure 6). Additionally, there were stated the parameters defining the bed and banks stability / failing processes for several bridge downstream cross-sections (figure 7).
We have to mention here that the employed data regarding the solid flow and temperature development along the considered simulation period (April 12th to May 12th, 2005) and also regarding the movable bed layers gradation curves and geometrical parameters, were only estimated with respect to site conditions as shown during site inspections, and so they are not supplied as measured and certified information. Some data range values were assimilated from example analysis offered by HEC-RAS 5.0.6 templates. Since the sediments transport numerical values were so adjusted according to the associated known liquid flow highwaters hydrograph, the foreseen results are expected in a feasible range of values for the studied river sector.
As regarding the initial and boundary conditions for the performed 1D numerical model, they were defined by the main Edit menu, employing the boundary conditions facility in Sediment Analysis sub-menu. The constant liquid flow steps duration (in hours), the constant flow values (in m^3/s) and

the computation increment (hours) were assigned to the entering cross section (river station 45.000) defined as BC Line. As the assimilated liquid flow hydrograph configuration show (figure 4), the given maximum value, designated as constant for the time interval from hour 240 to hour 264, is 1083 m^3/s. The hydrodynamical gradient of the river sector downstream part, known with the value of 0.000124, was assigned to the outgoing cross-section (river station 38.516).

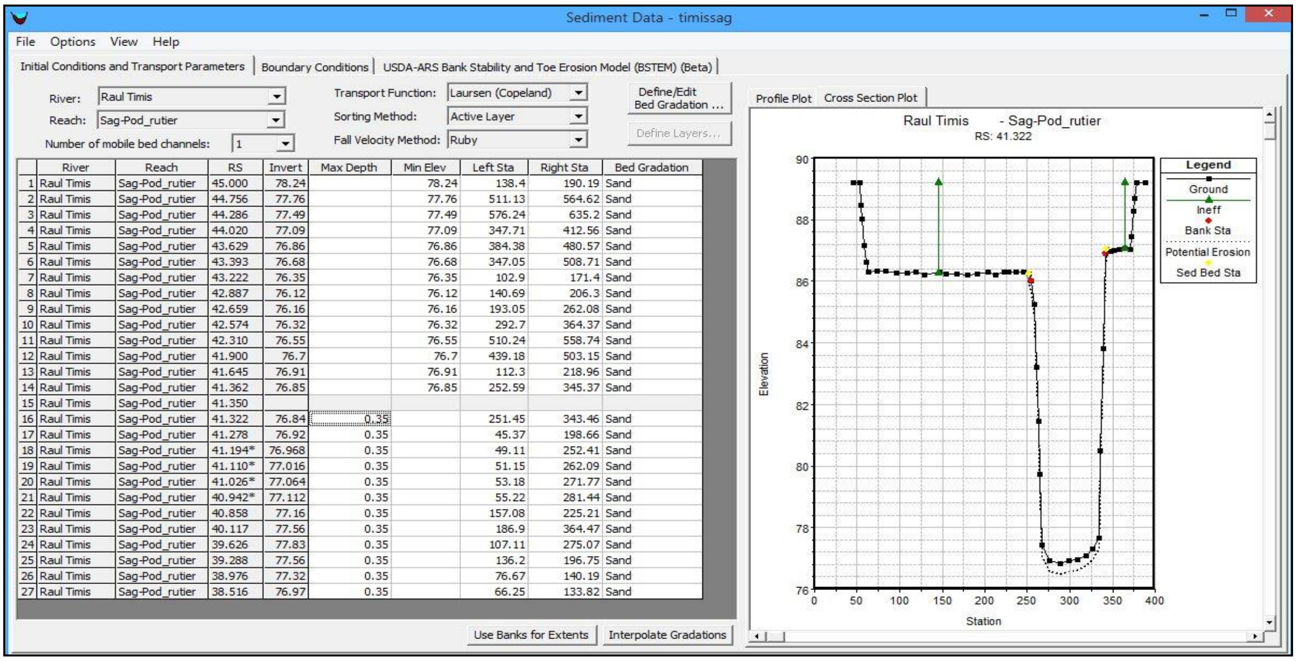

Fig. 5. Specific parameters and geometry data for sediments along the river sector and with a graphical detail in a bridge downstream cross-section (river station 41.322)

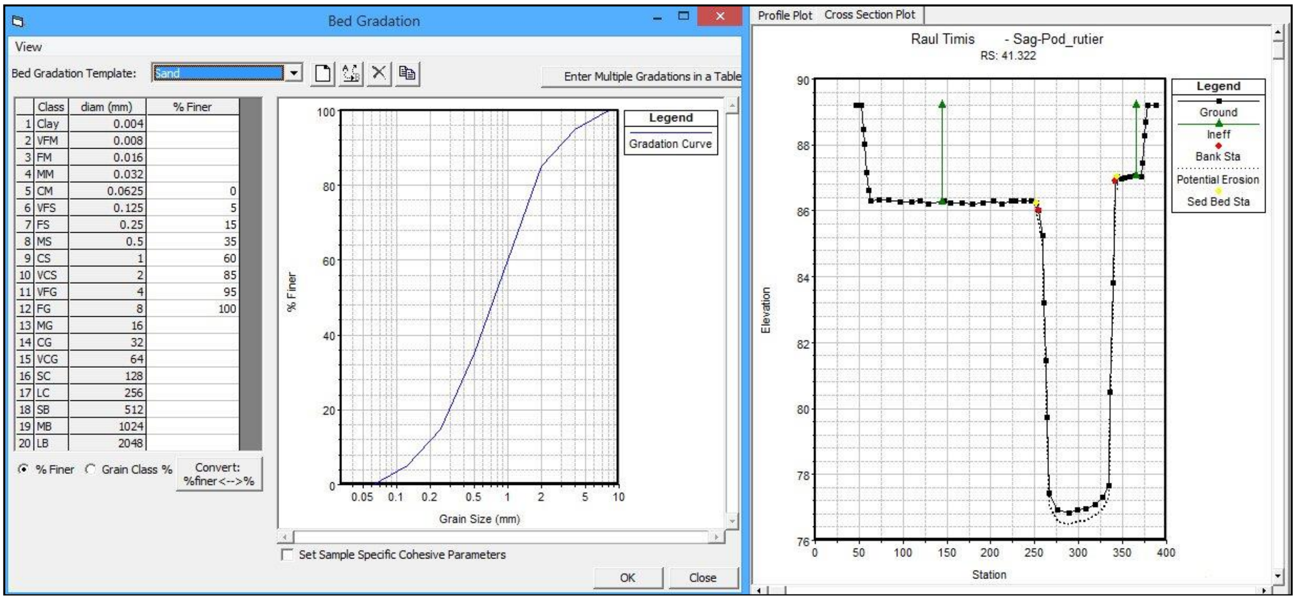

Fig. 6. Movable bed alluvia granulometry in the downstream area of the crossing bridge (river station 41.322)

The 1D sediments transport numerical model also requires the edit of daily solid flow quantity (tons/day) as associated to the liquid flow values by following a specific path from the main menu: Sediment Data → Data sediment – Sediment Series → Boundary Conditions → Rating Curve. The sediment load series is to be defined for each rating curve set, according to the solid material granulometry (figure 8). These values associated to the liquid flow levels are assigned to the river sector upstream entrance cross-section as sediments boundary condition.

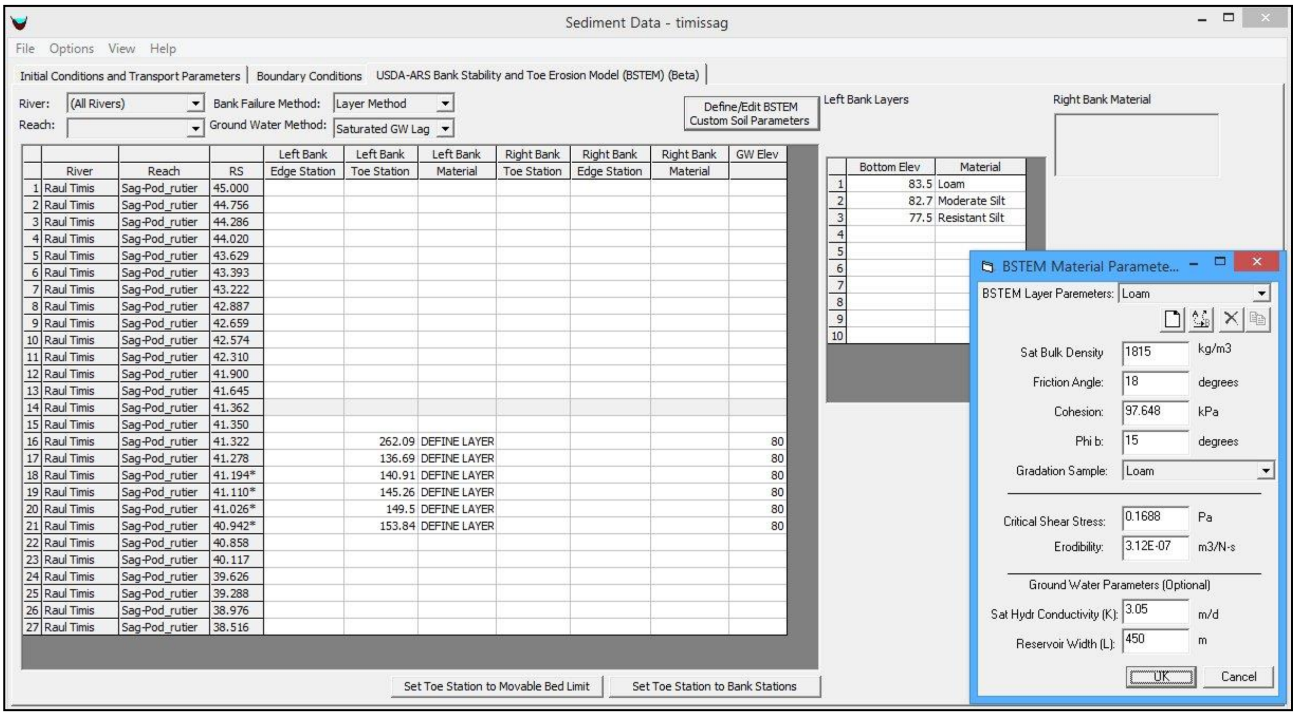

Fig. 7. Geometrical data and materials specific parameters regarding the river cross-sections

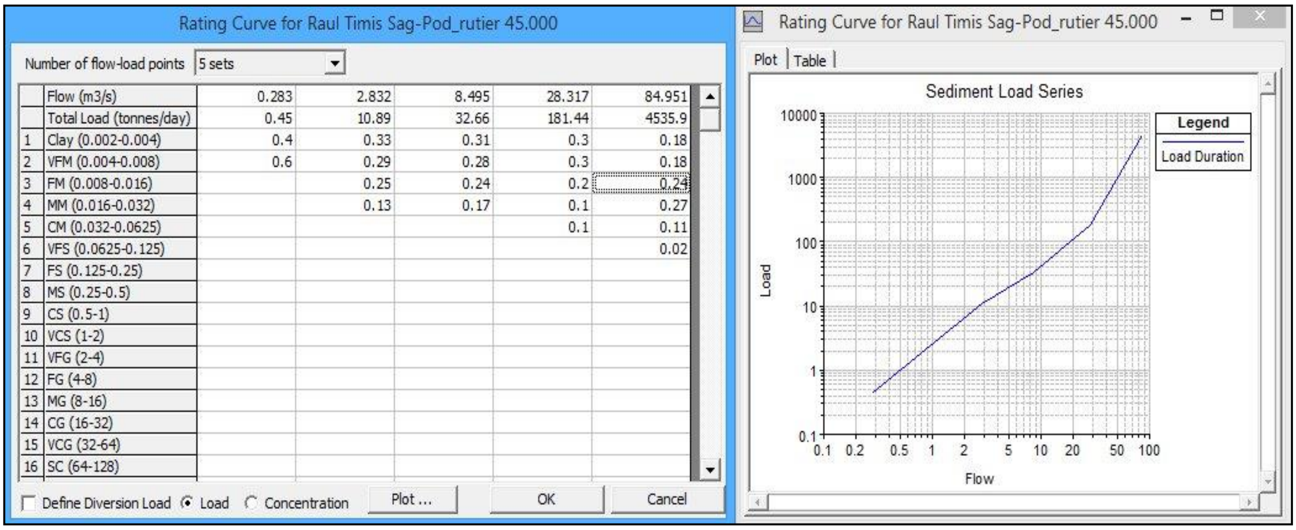

Fig. 8. Sediment load series definition in five sets as associated to liquid flow level

The actual numerical simulation of liquid and sediment transport by the considered Timiș River sector goes over a specific significant time interval in the spring of 2005, meaning from 06:00 on April 12th to 06:00 on May 12th.

3. Numerical simulation reached results

Constant and time dependent parameters, such as water surface levels, water flows and velocities, together with river-bed ground configuration development on the bridge downstream area, were obtained by running the numerical simulation.
The revealed numerical values are stored in specific files by performing the results postprocessing regular operations. The graphical representation in figure 9 stops at two pre-established illustrative moments, specifically the interval of maximum entering flow of 1083 m^3/s, April 25th (day 11), and the last constant flow interval of 149 m^3/s, May 12th (day 31).

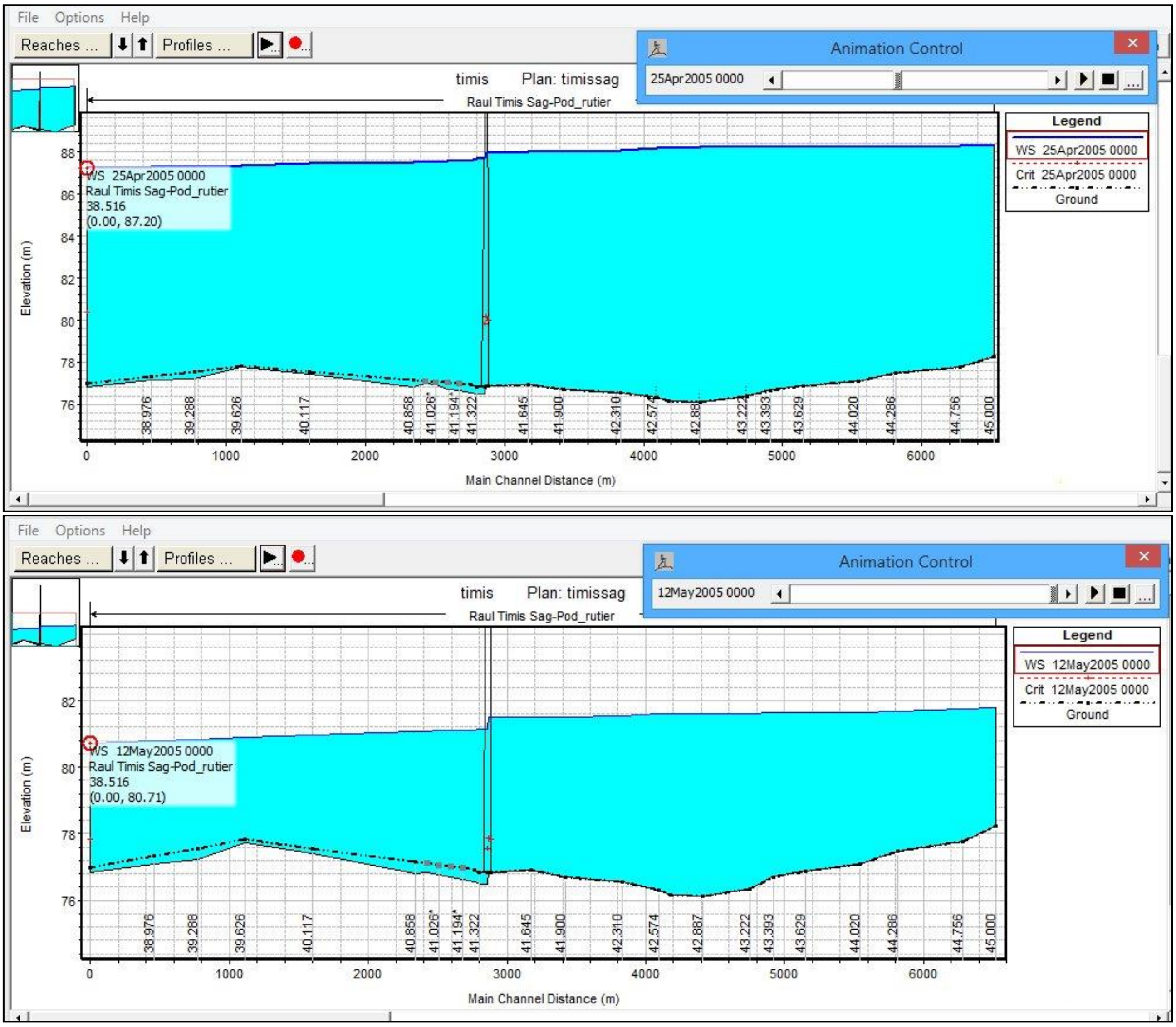

Fig. 9. Water surface and movable bed ground longitudinal development at two significant moments along the simulation period: upper - day 11 (April 25th), lower - day 31 (May 12th, 2005)

As regarding the results revealing the scouring process over time in the left upper river-bed downstream the crossing bridge, the following figure 10 brings up the geometrical configuration development of six specific cross sections (river stations 41.322; 41.278; 41.194*; 41.110*; 41.026*; 40.942*) of the most affected river stretch. There are indicated the initial (April 12th) and the final stage (May 12th) overlaid general configurations of the mentioned cross-sections, but also an upper left side detailed 11 steps phenomenon development (April 12th, 17th, 18th, 20th, 21st, 22nd, 28th, 29th and May 2nd, 6th, 12th) for each of these river stations.

By studying the visualised postprocessed scouring results from figure 10, one may point out the left side upper river-bed produced configuration (table no.1). There can be estimated the plan-view horizontal advance (Δx) and the elevation development (Δz) for each of the reference considered river cross-section. As with respect to the real scouring development due to the accidental highwaters hydrograph transited by the studied river sector along the special hydrologic phenomenon on the spring of 2005, there was possible to perform only late visual comparative estimations since any ground measurements were not available. Even if there is not possible to have a specific numerical judgement, one could still appreciate that the general estimated river-bed configuration closely simulates the real natural scouring phenomenon.

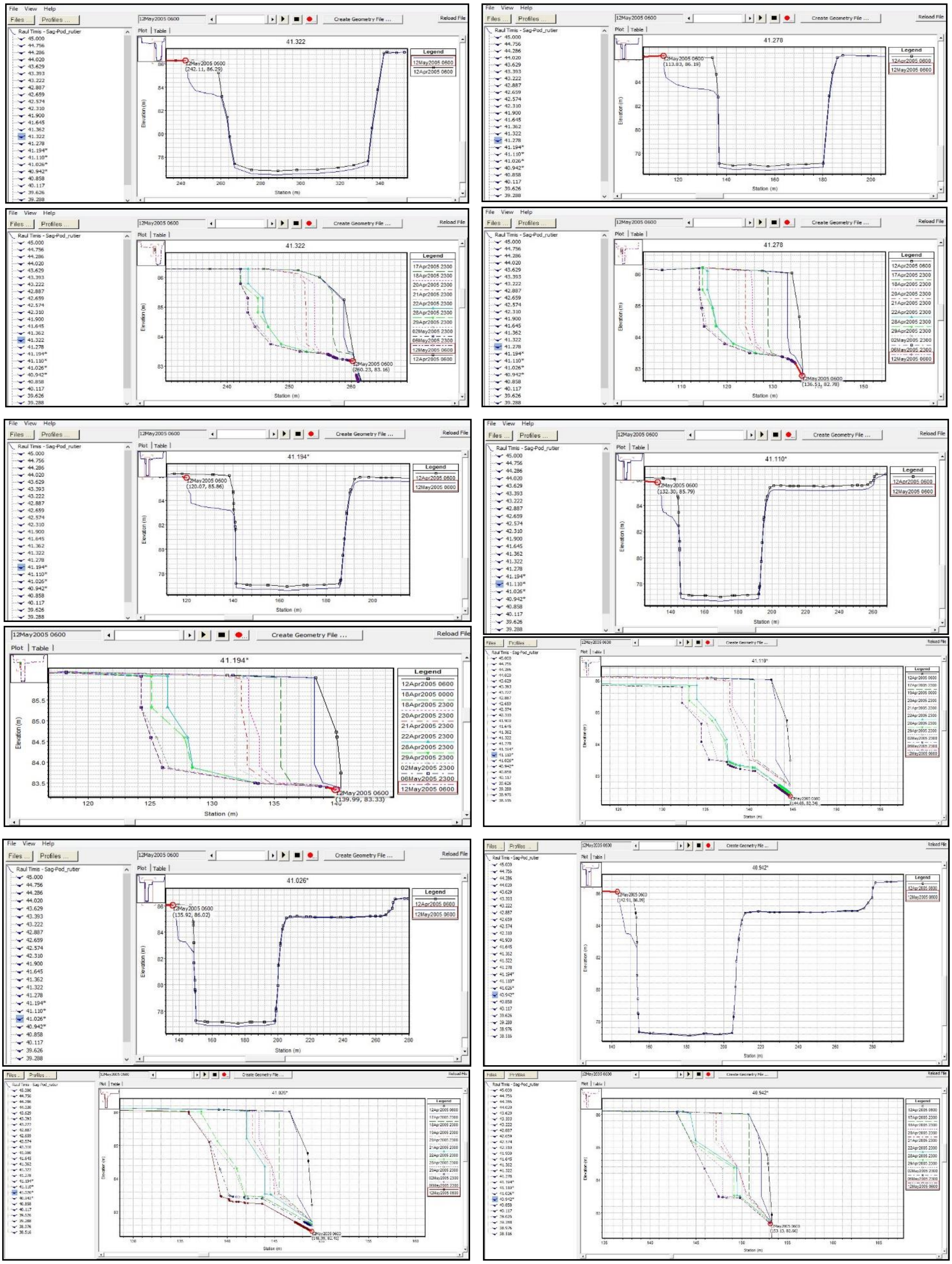

Fig. 10. Scouring process development on bridge downstream cross-sections 41.322; 41.278; 41.194*; 41.110*; 41.026*; 40.942*: beginning and ending moments overlaid general configurations, upper left detailed evolution along the simulation period (day no. 1, 6, 7, 9, 10, 11, 17, 18, 21, 25 and 31)

Table 1: Scouring geometrical values

River station	Scouring position (m)		Position advance Δx (m)	Level (mSL)	Elevation difference Δz (m)
41.322	Lower area	260.23	18.12	83.16	-3.13
	Upper area	242.11		86.29	
41.278	Lower area	136.51	12.68	82.78	-3.41
	Upper area	113.83		86.19	
41.194*	Lower area	139.99	19.92	83.33	-2.53
	Upper area	120.07		85.86	
41.110*	Lower area	144.69	12.39	82.34	-3.45
	Upper area	132.30		85.79	
41.026*	Lower area	148.99	13.07	82.41	-3.61
	Upper area	135.92		86.02	
40.942*	Lower area	153.13	10.22	82.66	-3.43
	Upper area	142.91		86.09	

4. Conclusions

The present analysis looked to estimate the river-course processes and so to numerically reconstruct the scouring phenomenon developed on a given sector of Timiș River, in the area of a six gaps national road concrete bridge, under special hydrological conditions that produced some natural river-bed morphological events. Besides the given accidental highwaters hydrograph and the available initial topography data, the study needed to correspondingly assume and adjust specific sediment parameters values due to lack of certified information.
One can first conclude that a sediments transport simulation under quasi-unsteady regime has to be considered in order to suitably fulfil the proposed task. As a result, by performing the liquid and solid transport 1D numerical modelling under the mentioned circumstances, there was still possible to estimate geometrical values defining a feasible and close to reality river-bed configuration.
Even if the site information allowed only a visual estimation of the numerical simulation results correspondence with respect to the real liquid - solid passage complex phenomenon, one may also conclude that the performed numerical modelling appropriately points out specific river natural events like banks failing (crumbling) and bed alluvia washing (scouring), accompanied by produced sediments flow transportation.
Further on, in order to determine general and local scouring ceasing along with gaps re-siltation, there can be appreciated as necessary the layout of a bottom-step at a proper distance downstream of the bridge structure.

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