Numerical Simulation of Sediments Transport AO a River Sector as Distorted by a Crossing Structure

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Abstract. The paper presents a 1D numerical modelling of sediments transit on Someș River downstream of its confluence with Agrij tributary, specifically for a 352 m sector affected by a driveway crossing bridge right outside of Jibou Town building area, about 25 km from Zalău Municipality in the North-West of Romania. There was considered a quasi-transitory flow regime as assimilated from a three years data available period of time, i.e. from August 1st, 1985, to July 31st, 1988. As considering the on-site findings and concluding general riverbed restoration suggestions of a technical expertise ordered by the Rivers National Administration, the performed numerical model comes in support of the technical solutions stipulated by a feasibility study conducted by the authors with respect to streamed balance achievement in the range of the mentioned bridge. Specifically, the following main interventions were implied: the accomplishment of a downstream bottom step to break the general scouring phenomenon in the structure vicinity and to produce the re-siltation of the central gaps, and the execution of two upstream river groins designated to lead the flow and carried alluvia towards the bridge central area. Thus, the numerical simulation performed by the help of HEC-RAS 5.0.6 specialized software package looks to establish the optimum location and geometry for the bottom step as correlated with bridge area re-siltation and general scouring on the modelled river sector. Specific structural results and flow parameters outcome – water surface level and velocity development – together with important general sediments transport information (e.g. flexible streambed configuration evolution) was concluded from the reached graphical output.

1. Introduction

The Town of Jibou is situated on the north-east part of Romanian Historical Province of Crișana, towards of Transylvania, as assigned to Sălaj County. It is placed on the left bank of Someș River, close to its confluence with the tributary Agrij River, at about 25 km north-east from the administrative municipality of the county, Zalău Town. The Someș River crossing by the east side connecting roadway (figure 1) is arranged by a suspension bridge of six gaps determined by concrete piers, the two middle gaps over the streambed and the side ones covering the flood plains. The bays have slightly variable gaps of about 33.40m, 25.40m, 26.30m, 24.90m, 25.80m and 23.80m, as going from left to right. The bridge stands on the two side abutments (upstream/downstream prolonged by cone-shaped quarters) and five piers (about 2.20m width, 5.20m length, 184.00mSL top level) founded by concrete blocks (top level at 175.05mSL).
The numerical model for the mentioned river site considers also specific data given by a technical expertise and a feasibility study covering the road bridge affected river sector [1] aside of Jibou Town. The feasibility study was concerned with the Someș River arrangement and consolidation in the bridge vicinity and concluded with the following proposed works: accomplishment of a bottom step downstream of the bridge aiming to help the river-bed re-siltation in the area of the middle gaps and to stop the general scouring phenomenon, development of side banks protections both upstream and downstream of the crossing structure, accomplishment of a couple of upstream river groins that would direct the flow towards the central part of the river-bed. The engaged ground configuration in the area, as given by the mentioned documentation, is indicated by the topographical plan view in the upper-right side of figure 1.

The employed water flows of different overpassing probabilities on the considered section of Someș River were supplied by the Mureș Branch of Romanian Waters National Administration: Q5% = 845m3/s, Q1% = 1320m3/s and Qm.a. = 125m3/s as the multiannual average flow. The hydrodynamic gradient is known as I = 2.75‰. The roughness coefficient for the river-bed was estimated in the range of 0.025…0.040, while for the side flooding plains in the range of 0.040…0.050.

Figure 1. Aerial view (Google Maps), topographical plan view [1] and general upstream view of Someș River crossing bridge (Google Maps) on the east side of Jibou Town

The numerical modelling of Someș River ground geometry, looking to analyse the quasi-transient flow regime, covers a given river sector and its corresponding sides of about 352.20m in length. A topographical data base reflecting the general plan view (comprising 371 measured points) and five cross-view profiles was developed for the area determined by the main river-bed and its side flood
The discrete numerical model was developed by the help of HEC-RAS 5.0.6 software package [2].

2. Numerical modelling of the liquid and solid flow transition under a quasi-unsteady regime

The graphical accomplishment of a 3D ground surface is usually achieved by the help of satellite imagery as given by the well-known Earth Explorer functional. Nicoară et al., 2018 [3] and 2019 [4], employ an accessible approach for the graphical processing of the topographical data as delivered by ground measurements. This approach engages a specialized topography tool for 2D graphic interpolation by the help of which a 3D shape type surface (a file of .shx extension) can be generated.

As regarding the present case, there was used a topographic data base file of 371 discrete points of given coordinates x, y and z (elevation level). The resulting 3D spatial surface is presented by the graphical image on the left side of figure 2. The surface was afterwards uploaded in ArcMAP 9.3 where was meshed by plane triangle discrete elements and so transformed in the final 3D digital space of TIN (Triangulated Irregular Network) type. In order to be recognizable by the RAS Mapper graphic processing module attached to HEC-RAS 5.0.6, the file has to be transformed into a grid type DTM (Digital Terrain Model) file [5,6]. The terrain representation (TIN) is to be converted as a point raster file of .FLT (FLoaTing) extension. Once adopting the geographic coordinates system, the created FLT natural terrain file is uploaded by RAS Mapper module as the right side of figure 2 shows under a HEC-RAS 5.0.6 representation frame. The facility comprises a graphic generation option for the actual numerical modelling by the software package (HEC–GEORAS 4.3), either for a 1D or a 2D approach, similar to the version engaged by GIS. Further on, the terrain 3D surface associated to the studied river sector as meshed by RAS Mapper becomes as shown in figure 3.

Figure 2. Plan view of the studied bridge site on Someș River: left- 3D spatial surface developed from the topographical measurements, right- 3D digital surface as final ground model

The 1D numerical model was afterwards generated by following specific operations in RAS Mapper regarding the watercourse path and cross-sections, the crossing structure and the geometry data. The model is visualised (fig.3) by employing the specific options (River, Cross Sections, Structures) and by activating the associated cross-section designation.
For further specific information regarding the sequential generating procedure, the conversion operation or about domain modelling (i.e. embankments adjustment, cross-sections definition etc.) one can search the cited material [3,8]. The graphical image in figure 4 presents the geometrical characteristics of the road crossing structure – bridge type structure of six gaps determined by five piers and two side-abutments. Looking for a comparative study, a second model version – designated as M2 (figure 4, right) – was developed by endowing the initial one – M1 (figure 3 and figure 4, left) – with the proposed bottom step [1] right downstream of the bridge structure. The actual location of this step was estimated by considering the M1 analysis results, while the final step elevation (0.95m) was reached by several optimization adjustments of the M2 analysis data (initially considering the step height of 0.80m).
As about the alluvia (sediment) transport (figure 5), due to lack of actual data on the specific watercourse, we must admit that this could be a difficult problem from the practical point of view. The available data is ambiguous, based mostly on relative assumptions [7]. In the same time the transport theory is mainly empirical and very sensitive to a large range of physical variables as model parameters, difficult to measure and estimate. HEC-RAS also comprises alluvia transport modelling capacities as one-dimensional movable boundary computations, successively adjusting the cross-sections geometry as a result of river deposits (sediments) dynamics.

The graphical presentation in figure 6 shows the specific facility for the flow hydrograph uploading in the quasi-unsteady approach as corresponding to the assimilated time period, i.e. from August 1st, 1985, to July 31st, 1988, while the figure 7 illustrates the associated temperature series uploading.

The quasi-unsteady flow model developed in HEC-RAS 5.0.6 involves three specific files, one for the constant or unsteady flow, one comprising the geometry data and a third one merging the data ones. The sediments analysis, constant or unsteady, requires also a fourth distinct file that covers the given alluvia information, as figure 8 employs. Some demanded parameters are specified for each cross-section of the model. The following options were engaged for the sediment transport analysis: the Yang model as transport function, the Thomas layers mixing method for the river-bed sorting and armouring, and the Rubey model for the fall velocity computing method.
The Sediment Data facility is considered in the main edit menu in order to upload the corresponding considered records (figure 8). Three facilities are available there, i.e. Initial Conditions and Transport Parameters, Boundary Conditions, and USDA-ARS Bank Stability and Toe Erosion Model (BSTEM). The first two are compulsory, while the third one is to be considered in case of analysing the banks deteriorating processes and so not required for the conducted sediment transport study. As regarding the moving river-bed, there were defined six characteristics with respect to layers gradation, labelled as Sample 1… Sample 6, by considering specific granulometry curves (as figure 9 presents for the crossing bridge section). As a special note, we need to mention that, due to lack of authorised measurements or field experimental information, the data base covering the solid flow development and the river-bed geometrical parameters and gradation curves along the studied river sector, was built mainly by general estimations for theoretical purpose of conducting the proposed modelling. Essentially, the engaged numerical values were estimated based on suggested phenomenon developments considered by other similar modelling performed with the specific modules of HEC-RAS. The numerical values were successively altered looking to reach possible levels for the transited flows along the analysed sector of Someș River on the peripheries of Jibou Town.

As about the involved boundary conditions, the 1D numerical model requires the engagement of the corresponding facility (BC Line) in Sediment Analysis sub-menu. The time period (in hours) of constant flow, the computational increment (hours) and the flow values (in m$^3$/s) are assigned to the river sector entering cross-section (352.2, figure 10). Along the constant flow period, a time subdivision is defined in accordance to the flow numerical value (the subdivision value decreases with the increase in flow stepped value), as can be noticed by checking the “Compute computation increments based on flow” option. As attached to the upstream cross-section (352.2), the liquid flow hydrograph on the considered sector of Someș River presents the maximum value of 226.53 m$^3$/s. The hydro-dynamic gradient of 0.00275 was assigned to the outgoing downstream cross-section (6.4).
Figure 7. Associated temperature series from August 1st, 1985, to September 6th, 1989.

Figure 8. Sediment geometrical data and specific parameters associated to the cross-sections
Figure 9. Gradation curve of the moving river-bed as corresponding to the subjected crossing bridge section (162.9) on Someș River

Further on, following a specific menu approach for boundary condition assignment to the upstream cross-section (Sediment Data → Data sediment → Sediment Series → Boundary Conditions → Rating Curve), the sediment transport 1D numerical model requires the edit of several series of values for the liquid flow to which the total solid daily load (tons/day) is associated (figure 11). There is also specified the gradation fraction contribution as corresponding to the defined solid material granulometry, for each of the defined series.

Figure 10. Boundary conditions definition attached to the upstream entering cross-section – flow series associated to the considered time period and computational increment
The actual liquid and sediment flow transition numerical simulation spreads over a given period of time, i.e. from 01:00 on August 1st, 1985, to 23:00 on July 31st, 1988. Afterwards, a second 1D model version M2 was additionally established by improving the base one M1 with a bottom step structure (of 0.95m final height, designated as “54”) delimitated upstream and downstream by cross-sections 63.5 and 46 respectively. The M2 model version was produced by copying the M1 files in a separate folder where from were uploaded and altered as mentioned from the geometrical point of view in HEC-RAS. All the previously considered boundary conditions are preserved.

3. Numerical simulations and comparative results

Constant and time dependent parameters – water surface levels, flow and velocity – over the entire domain of the base 1D numerical model M1 were revealed by running the simulation. The analysis looked to determine the geometrical configuration of the moving river-bed along the longitudinal profile. This configuration presents an inflection point, delimiting the silting and scouring processes along the considered river sector, in the crossing bridge downstream area. It was so estimated the bottom step structure location in the area of the model cross-sections 63.5–46. By running further successive simulations on the bottom-step enriched model version M2, the structure height was established of 0.95m as optimum for the river-bed re-silting process under the assumed sediment conditions. Along with the final simulation, the corresponding hydraulic parameters were revealed for the M2 version too. Following the numerical results graphic postprocessing operations for the two modelled versions M1 and M2, the specific output files were created and consequently individually visualized. Several significant comparative representations at specific moments of given constant water flow are considered: 2.83m³/s on August 18th, 1985, 25.485m³/s on January 8th, 1986, 226.53m³/s on January 30th, 1986, 2.83m³/s on August 5th, 1986, 186.79m³/s on February 20th, 1987, and 2.83m³/s on July 26th, 1988.

Figure 11. Definition of the five series of values regarding the sediment load upon the liquid flow levels

Figure 12 shows the graphical development of water surface and moving river-bed as a longitudinal profile along the river thalweg for the M2 model version at several time moments of the total simulated period, a significant moment being the ending one, on July 26th, 1988. There was noticed from the numerically delivered level space and time development that on January 30th, 1986, the riverbed minimum level of 174.78mSL is produced at the downstream side of the crossing bridge (RS 142.5), meaning a beginning scouring of about 174.78 – 175.05 = -0.27m. Afterwards the scouring diminishes and even more changes to a siltation tending to grow that reaches towards the end of the
simulation period the relative height with respect to the foundation top of about \( 175.56 - 175.05 = +0.51 \text{m} \).

Figure 1. Moving river-bed and water surface elevation longitudinal development for the M2 model version at several time moments along the simulation period.

The graphical representation in figure 13 reveals that the moving river-bed on the upstream side of the crossing bridge (RS 153.7) of the base model version M1 shows a maximum scouring of about -0.26m in the beginning of the simulation period which diminishes in time towards about \( 174.95 - 175.05 = -0.10 \text{m} \) at the end. In comparison, the M2 model version leads to results (figure 14) that show a river-bed development from the maximum scouring of about -0.29m on the upstream side of the crossing bridge (RS 153.7) which gradually diminishes and further on transforms into a growing siltation of about \( 175.30 - 175.05 = +0.25 \text{m} \) towards the simulation period end.

Table 1. Moving river-bed development at cross-section “148”

| flow duration (hours) | flow (m³/s) | model version | water surface level (mLSL) | river-bed level progress (m) | bed process type |
|----------------------|-------------|---------------|---------------------------|-----------------------------|----------------|
| 746.4                | 2.83        | M1            | 174.90 – 175.05 = -0.15   | scouring                    |                |
|                      |             | M2            | 176.08                    | 175.05 – 175.05 = 0.00      | stagnation     |
| 129.6                | 25.485      | M1            | 174.95 – 175.05 = -0.10   | scouring                    |                |
|                      |             | M2            | 176.35                    | 175.42 – 175.05 = +0.37     | siltation      |
| 8.88                 | 226.53      | M1            | 174.90 – 175.05 = -0.15   | scouring                    |                |
|                      |             | M2            | 174.80                    | 175.80 – 175.05 = -0.25     | siltation      |
| 129.6                | 2.83        | M1            | 175.30 – 175.05 = +0.25   | siltation                    |                |
|                      |             | M2            | 176.08                    | 175.40 – 175.05 = +0.35     | siltation      |
| 36                   | 186.79      | M1            | 174.90 – 175.05 = -0.15   | scouring                    |                |
|                      |             | M2            | 177.22                    | 175.30 – 175.05 = +0.25     | siltation      |
| 720                  | 2.83        | M1            | 175.30 – 175.05 = +0.25   | siltation                    |                |
|                      |             | M2            | 176.05                    | 175.66 – 175.05 = +0.61     | siltation      |

As foreseen, the reached results allow us to say that the bottom step of the final estimated height and location is both mandatory and adequate for the river-bed relative stabilization in the crossing road bridge area of influence on Someș River, outside of Jibou Town.
4. Conclusions

As considering the performed numerical modelling of liquid and sediment flow transition by the Someș River sector in the crossing road bridge area, east side of Jibou Town, the following main conclusions can be pointed out with respect to the river-bed situation and developing processes:

- there is required a bridge downstream bottom step of 0.95m optimum height in order to determine the scouring stoppage and bed re-siltation especially in the threatened middle gaps space;
- the discrete numerical simulation proved to be an appropriate approach for estimating the inflection point delimiting the silting-scouring sections on the river-course, specifically in the downstream area of the crossing bridge;
- an optimum height of a river bottom step, as the one customizing the M2 numerical model version, can be established by considering a specific goal with respect to the moving river-bed development and consequently proceeding to successive flowing simulations as associated to the watercourse geometrical, hydrological and sediment loading characteristics;
- the estimated bottom step structure, of proper location and size, determines the river-bed relative stabilization, while additional safety running requirements (according to enforced national regulations) are to be fulfilled by constructive measures such as specific bank protections over upstream and downstream lengths of 50 to 100m from the bridge structure.
References

[1] A. Băcov, E. Fülop, G. I. Lazăr, *Consolidare pod peste Râul Someș în vecinătatea localității Jibou, Etapa: Calcule hidraulice și studiu de fezabilitate / Someș River bridge consolidation in the vicinity of Jibou Town, Stage: hydraulic approach and feasibility study*, Contract no.004/1997, Beneficiary: Sălaj County Administration.

[2] G. W. Brunner, *HEC–RAS, River Analysis System, Release Notes, Version 5.0.6, US Army Corps of Engineers*, 2018.

[3] Ş. V. Nicoară, G. I. Lazăr, A. T. Constantin, *Comparative Study of a 1D and 2D Numerical Analysis Modelling a Water Flow at a River Confluence under Accidental High Waters*, HIDRAULICA - Magazine of Hydraulics, Pneumatics, Tribology, Ecology, Sensorics, Mechatronics, ISSN 1453 – 7303, No.4/2018.

[4] Ş. V. Nicoară, G. I. Lazăr, A. T. Constantin, *Computer analysis of water flow transition under existing conditions on a river sector in the range of a bridge structure*, HIDRAULICA - Magazine of Hydraulics, Pneumatics, Tribology, Ecology, Sensorics, Mechatronics, ISSN 1453 – 7303, No.1/2019

[5] ***, *HEC-RAS, River Analysis System, Supplemental to HEC-RAS Version 5.0, User's Manual, Version 5.0.4.*, US Army Corps of Engineers, 2018

[6] G. W. Brunner, *Combined 1D and 2D Modelling with HEC–RAS, Version 5.0, US Army Corps of Engineers*, 2016

[7] G. W. Brunner, *HEC–RAS, River Analysis System, Hydraulic Reference Manual, Version 5.0*, US Army Corps of Engineers, 2016