Hydraulic Computer Analysis of a River Sector Under Altered Flowing Regime Due to an Existing Bridge and Suggested Specific Correction Works

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Abstract. The paper presents a 2D numerical modelling of the water flow transit under an altered regime on Strei River, specifically for a 633m stretch influenced by a driveway crossing concrete structure of four gaps (about 71m total span) on a national road outside of Deva Town, Romania. The analysis considers a possible (and requested by specialised regulations) accidental highwaters flow development as assimilated from a specific hydrologic phenomenon that occurred on site during the special spring season of 2000. Taking into consideration the findings and general flow improvement suggestions of a technical expertise ordered by the rivers national administration, the present developed hydraulic model follows the technical recommendations of a formerly feasibility study with respect to streambed correction in the range of the mentioned bridge, specifically the downstream accomplishment of a bottom step (for scourings re-siltation) and two left side river groins (to direct the stream flow towards the central span of a following railway bridge, not covered by present model), accompanied by banks protection and alluvia deposits removing works. Under the given flow and geometry conditions, the study accomplished by the help of HEC-RAS 5.0.6 specialized software package looks to estimate the water surface level and velocity development in space and time, and so to draw the future state of flow transition along the analysed sector. As about the simulation output, the most important conclusions are that the riverbed would be able to discharge the significant flow of 0.1% overrunning probability at a maximum surface level below the structure safety values. In the same time, the reached velocity and particle tracking visualizations suggest a more stable and efficient riverbed time behaviour.

1. Introduction
The Strei River crossing by the national driveway DN7 at km376+818 is done by a four gaps concrete bridge. The two middle gaps, each of about 28m wide in-between the abutment piers faces and 24m in-between the foundation blocks, cover the streambed opening while the side ones, of about 19m / 17m wide, lean over the floodplains towards the framing embankments (figure 1). The side abutments show an upstream/downstream elongated geometry ending by cone quarters. The intermediate supporting abutment piers are about 1.60m thick, 8.00m long and 2.70m high (above the foundation blocks upper level, 93.80mSL).
Figure 1. Driveway concrete bridge on DN7 at km376+818 over Strei River, upstream (left) and downstream (right) views

The numerical modelling of the presented site is based on a technical expertise [1] and a feasibility study [2] regarding the covered Strei River sector, both documentations developed by the university hydraulic arrangements department. The feasibility study had as objective the Strei riverbed rearrangement and consolidation in the mentioned bridge influence area and so concluded on the following specific works: accomplishment of a downstream bottom step to determine general scouring ceasing and the middle-left gap re-siltation, accomplishment of two downstream groins looking to direct the general flow towards the central part of the succeeding railway bridge (about 300m from the considered bridge), riverbed calibration by excavating the expanded alluvia deposits and upstream / downstream banks protections respectively. The altered river valley configuration in the bridge area is presented in figure 2.

The maximum water flows of different overrunning probabilities on the considered bridge section on Strei River show the following values as supplied by the Romanian Waters National Administration – Mureș Water Branch: $Q_{5\%} = 480\text{m}^3/\text{s}$, $Q_{2\%} = 590\text{m}^3/\text{s}$, $Q_{1\%} = 680\text{m}^3/\text{s}$ and $Q_{0.1\%} = 695\text{m}^3/\text{s}$. The high-waters hydrograph was provided as correlated with the 1% overrunning probability flow. The hydrodynamic gradient corresponding to low waters was known as 0.62‰, while the value related to high-waters is 2.4‰. The estimated roughness coefficient is 0.025…0.040 for the streambed and 0.040…0.060 for the side flooding banks.

The numerical modelling of the altered riverbed, which considers a sector of about 633m length, was performed by the help of the performant software package HEC-RAS 5.06 [3].

There was assembled a database reflecting the 1268 points of the topographic site plan and the 14 crossing profiles (see locations in figure 2) that points out the river-valley morphology, as corresponding to the river sector path and the side flooding-plains.
Figure 2. Topographic plan view of Strei River site [2] corresponding to the driveway bridge, showing the proposed geometrical configuration
As regarding the numerical modelling of a river sector morphology, the 3D terrain graphical representation is usually accomplished by the satellite imagery given in the well-known Earth Explorer. Nicoară et.al. (2018) [4] follows a practical procedure of topographical data processing, employing a 2D graphical interpolation (on Ox and Oy directions) that further on leads to the generation of a 3D type shape in a .shx extension file. For this specific case, there was engaged a file comprising the topographical measurements (the 1268 points of x, y and z coordinates defining the 3D surface as presented in figure 3-left). As opening the file in ArcMAP 9.3 [5], the appointed domain was divided by discrete spatial surfaces of triangular shape obtaining the final digital outline type TIN (Triangulated Irregular Network, as presented in figure 3-right). Additionally, some upgrading was accomplished with respect to streambed in the specific cross-sections associated to the bridge and the outgoing area of the river sector.

![Figure 3. View of the Strei River sector site plan, 3D topographic surface (left) and its digital outline (right)](image)

In order to be recognized by the graphical processing module RAS Mapper of HEC-RAS 5.06, the image had to be converted to an accessible DTM (Digital Terrain Model) grid type file [4, 6, 7]. The final outline of the natural terrain configuration of .FLT extension was then uploaded by RAS Mapper (see the graphic representation of figure 4). Additional information regarding the sequential generating procedure or the conversion operations is presented by Brunner (2016) [7] and Nicoară et.al. (2018) [4]. In the end, we may consider that even the digital model is based on a relatively reduced number of topographically supplied points, it still adequately fulfils the requirements of a 3D surface to represent the analysed river sector.

### 2. Development of the 2D numerical model

As demanded, the 3D representing surface of the altered river sector configuration considers the riverbed as calibrated and endowed downstream with a crossing bottom step and two river groins against the left bank. All these simulated elements (see figure 2) were added to the bi-dimensional interpolated model with HEC-RAS [3].
The 2D analysis domain labelled as “pod_strei_epiuri” was generated by considering the terrain model presented on the right of figure 3. By engaging the 2D Flow Areas facility in the explorer type window (figure 4, left), the analysis domain contour was drawn and then saved as “S2D”. Initially, there was set a grid spacing of $Dx=10\text{m} \times Dy=10\text{m}$, and so the associated points and the corresponding spreadsheets of properties were generated – Generate Computations Points / Compute Property Points – and saved. Afterwards, the grid was locally enhanced at a spacing of $Dx=5\text{m} \times Dy=5\text{m}$ for the streambed stretch (figure 4, right). After defining a breaking line along the bridge axis, a further grid enhancement is performed for the crossing structure area at a spacing of $Dx=2.5\text{m} \times Dy=2.5\text{m}$ (see a detailed view in figure 5).

![Figure 4. Plan view of the 3D terrain for the analysed Strei River sector: general grid definition (left) and grid local enhancement (right)](image1.png)

![Figure 5. Detailed view of the river site in the bridge area](image2.png)
The grid breaking line is needed from two reasons, i.e. to facilitate the cells alignment along the bridge axis direction and also to help at the definition of a connecting structure (a linking element between two specific areas inside the 2D digital model). In our case, the connection structure along the considered breaking line and defined by SA/2D Area Conn facility will bring the driveway bridge geometry to the model. The considered bridge geometry and some hydraulic specifications are presented in figure 6.

As about the boundary conditions of the 2D numerical model, they were defined in the main menu of Geometric Data window by considering the line type boundary condition under SA/2D Area BC Lines option (figure 7). Two paths were considered for the analysed 2D domain, one along the upstream edge – BC_S2D_11 – to which the high-waters hydrograph and the water energy gradient were assigned, and the other one along the downstream edge – BC_S2D_22 – where the water hydrodynamic gradient was specified. The high-waters hydrograph configuration on the given site on Strei River as generated for the flow of $Q_{0.1\%} = 695\text{m}^3/\text{s}$ is presented in figure 7. The associated water energy gradient is 0.0024, a value considered for the downstream boundary hydrodynamic gradient too.

The actual numerical simulation of flow transition was set as along the special period of time starting from April 25th, hour 00:00, to April 29th, hour 03:00, 2000, corresponding to a registered special hydrologic phenomenon. The analysis was run with a time step of 0.1 seconds and a mapping interval of 10 seconds, while the results storing was set to every 10 minutes.

**Figure 6.** Geometric and hydraulic elements defining the bridge structure as connexion element
3. Numerical simulation and results
Specific parameters – water levels, flows and velocities, either steady or time dependent, were revealed for each cell of the 2D numerical model by running the designed simulation. Following the graphical post-processing operations, the numerical results were stored in distinct files where can be visualized as user requires, for specific cells or along defined paths, by engaging the RAS Mapper facility [7].

The 2D graphical presentation of results considers several specific moments along the simulation period in order to point out the outcome corresponding to the increasing water flow values of successive overrunning probabilities, i.e. $Q_{\text{start}} = 180 \text{m}^3/\text{s}$, $Q_{5\%} = 490 \text{m}^3/\text{s}$, $Q_{2\%} = 590 \text{m}^3/\text{s}$, $Q_{1\%} = 680 \text{m}^3/\text{s}$ and $Q_{0.1\%} = 695 \text{m}^3/\text{s}$ (figure 8). The significant options regarding the particle’s trajectories and the water surface elevation longitudinal development are selected.
Figure 8. Water surface elevation development and overlaid particles trajectories at five specifically defined moments along the simulation period, i.e. 00:12 (corresponding to a flow of about 181.2m³/s), 03:32 (480.2m³/s), 04:41 (590.1m³/s), 06:24 (680.7m³/s) and 08:17 (693.2m³/s).

The general head from model entering to its outgoing sections and the water surface drop at the bridge structure can be established from the water surface elevation development at the considered moments (table 1).

Table 1. A slightly more complex table with a narrow caption.

| moment       | station | model entering | Water surface elevation (mSL) | model outgoing (head, m) |
|--------------|---------|----------------|-------------------------------|--------------------------|
| 00:12 (181.2m³/s) | 94.083 | 93.695         | 93.643 (5.2)                | 92.346 (1.737)          |
| 03:32 (480.2m³/s) | 95.211 | 94.655         | 94.502 (5.3)                | 93.565 (1.646)          |
| 04:41 (590.1m³/s) | 95.543 | 94.909         | 94.759 (5.0)                | 93.888 (1.655)          |
| 06:24 (680.7m³/s) | 95.799 | 95.093         | 94.977 (11.6)               | 94.455 (1.344)          |
| 08:17 (693.2m³/s) | 95.829 | 95.115         | 94.984 (13.1)               | 94.189 (1.640)          |

The following figure 9 shows the particles trajectories for the significant moment when the maximum flow of about 695m³/s is reached, once as a detail overlaid against the water depth development and also as overlaid on the water velocity distribution. There is also produced the longitudinal profile along the estimated accidental path appears to open as a left bank by-pass.
Figure 9. Overlaid particles trajectories views at the specific moment of 08:17 corresponding to the 693.3m³/s flow, against water depth development (left) and against water velocity distribution (middle); left bank by-pass longitudinal profile (right)

The maximum values of the water velocity rise in the bridge downstream vicinity to about 5.40m/s due to the crossing structure influence upon the upstream surface elevation increase.

4. Conclusions

Following the hydraulic numerical modelling of the Strei River sector in the driveway bridge influence area, two specific conclusions came out as of particular importance. There was established that the analysed sector riverbed and its side floodplains present the proper discharging capacity, even for the maximum stipulated flow of 1‰ overrunning probability, meaning about 695m³/s. Under the mentioned circumstances, the maximum water level towards the bridge upstream face reaches up to about 95.2 mSL which leaves a proper guard height below the abutments top at 96.5mSL.

At the same time, one can appreciate that the considered measures for riverbed correction and improved water flow transition – bridge downstream bottom step, two downstream left bank groins, streambed calibration and banks protections – prove to fulfil in short time their objective.

References
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