IMPACT OF EXPANSION AND CONTRACTION COEFFICIENTS ON WATER SURFACE PROFILES

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Abstract: T*he losses due to the contraction and the expansion of the flow between the upstream and downstream cross sections of a bridge determine the calculation of the water surface profile. Manning's equation is used to calculate friction losses, and all other losses are described in terms of a coefficient times the absolute value of the change in velocity head between adjacent cross sections. HEC-RAS software developed by the US Army Corps of Engineers Hydrologic Engineering Center (HEC) River Analysis System (RAS) is one of the most used free software for calculating surface water profiles in rivers. Calculation of surface water profile in bridge areas involves detailed analysis on the expansion and contraction coefficients impact. The purpose of this study is to analyze and determine the changes in water level, depending on the expansion and contraction coefficients, in the area of the 4 existing bridges, on the measured section of the river course. For the correct hydraulic modeling and difference analysis of water profile, the depths were measured on a 35 km sector of the Siret river and a bathymetric model was created. Results show that an increase of the expansion and compaction coefficient with 0.2 units leads to differences of approximately +/- 20 cm in calculating the surface water level, at a flow rate of 1000 m^3/s.*

Keywords: Siret River, bridge hydraulics, expansion coefficient, contraction coefficient

1. Introduction

The flooded surface of a river depends on a correct created hydraulic model. Furthermore, the HEC-RAS hydraulic model is geometrically influenced by a series of parameters that require calibration. One of these elements is influenced by the bridges or other high-raised construction (like transportation bands) above the water profile which cross the entire width of the river [1,2]. Usually, these structures are built on strength pillars of a certain width and height. The resistance pillars directly influence the hydraulic modeling, representing an obstacle to the uniform flow in the major or minor riverbed channel [3]. Special attention is given to bridges, as they lead to a contraction or expansion of the flow, downstream or upstream of these structures. One of the challenges is the prediction of the energy loss by one-dimensional modeling in the upstream area of the contraction of the flow and the downstream area of the expansion of the flow [4,5].

In order to analyze the energy losses in the area of a bridge 4 cross sections must be defined in geometric HEC-RAS model: 2 upstream and 2 downstream cross section wich are digitized at approximately equal distances between them. The 2 cross sections near the bridge, upstream and downstream, are defined as close as possible to the built structure of the bridge. The vector describing the bridge route is digitized based on the digital elevation model, so as to describe the topographic points that have the maximum elevation. Figure 1 represents the conceptual illustration of the energy loss in expansion and contraction bridge areas.

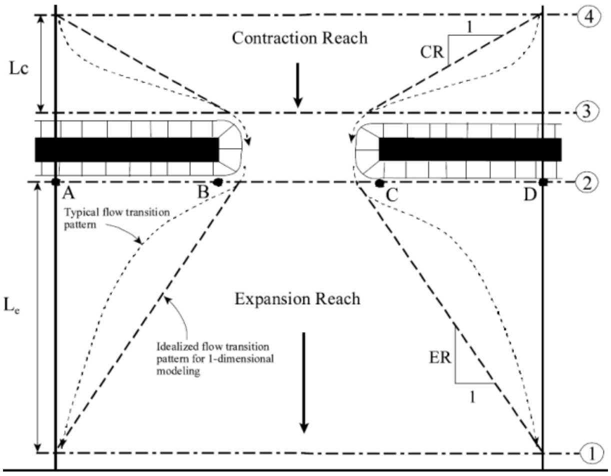


Figure 1: *The contraction and expansion of flow as it passes through a bridge or culvert opening at a roadway crossing* [6]

The energy loss is calculated according to the contraction or expansion coefficient according to the general mathematical equation 1 [7].

$$h_e = C_e \left| \frac{a_1 V_1^2}{2g} - \frac{a_2 V_2^2}{2g} \right| \qquad (1)$$

where: α_1 - kinetic energy correction coefficient at the downstream cross section; α_2 - kinetic energy correction coefficient at the upstream cross section; C_e - coefficient of expansion; g - acceleration of gravity (m/s^2); h_e - minor loss due to channel expansion at a cross section (m); V_1 = average velocity at the downstream cross section (m/s) and V_2 - average velocity at the upstream cross section (m/s).

The length of downstream expansion (Le) is about 3-4 times longer than the upstream contraction (Lc) and is determined by the 4:1 expansion ratio, for an ideal model that can be obtained under laboratory conditions [8]. As can be seen in figure 1, the contraction is between cross sections 3 - 4, and the expansion takes place between the cross sections 2-1. The expansion and contraction coefficients are used to determine the energy losses upstream and downstream of the bridge. The energy losses for the expansion areas are higher than the energy losses in the contraction areas. For the analysis of the energy losses in the areas where are bridges, the expansion coefficient of 0.3 and the compaction coefficient of 0.1 are usually used. The specific values of the compaction (C_c) and expansion coefficients (C_e) for different types of energy losses are described in Table 1.

Table 1: *Contraction and expansion coefficients* [7]

Class	Description	C_c	C_e
A	No transition loss computed	0.0	0.0
B	Gradual transition	0.1	0.3
C	Typical bridge sections	0.3	0.5
D	Abrupt transitiomn	0.6	0.8

2. Study area

The study area is 35 km river section upstream along the lower Siret River, section Galati – Sendreni – Independenta, from the confluence with Danube River, up to Independenta Village and forms the border between Galati and Braila Counties [9]. Figure 2 shows an open street map view of the study area that was under discussion. From research point of view, this section of watercourse represents an unmeasured from bathymetric and topographic point of view area, and it is of real scientific interest to analyze them.

Figure 2: *Study area: Siret water course section located between the yellow lines.*

3. Materials and methods

The study area was measured from bathymetric point of view to create a digital elevation model for the minor riverbed. The depth and land surveying measurements were made between 22.03.2017 to 01.04.2017. The bathymetry data as can see in Fig. 3 were collected using a boat-mounted single beam acoustic depth sounder (SBES) linked to a real-time kinematic (RTK) global positioning system (GPS), which can provide sub-decimeter accuracy for the surveyed points [10]. The left and right bank points was surveyed with a Trimble 5" instrument and RTK GNSS South S82-V with a +/- 5 cm horizontal positioning accuracy and +/- 7cm vertical accuracy.

Figure 3: *Single beam sonar for depth measurements, RTK GNSS linked with sonar and total station for bank points measurement*

Figures 4 and 5 represent the bathymetric path (blue points) and land surveying of the right and left banks of the river (yellow points). Also, here were measured the topographic details of bridges and raised construction meet on this section of river.

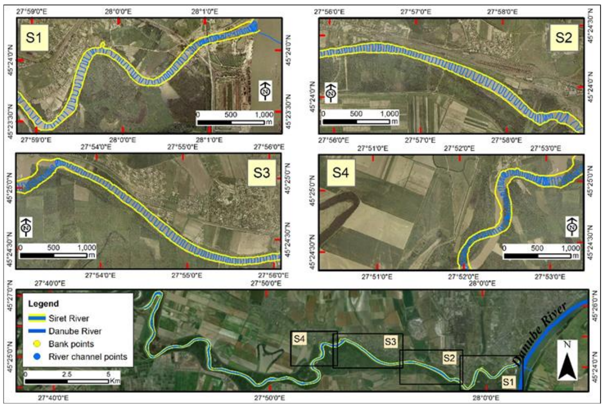


Figure 4: *First 4 section from downstream to upstream of depth and land surveying measurements*

According to many researchers [11,12] the best way to collect bathymetric data is the transversal path way. The maximum distance between the cross-section ranges from 25 to 100 m. This fact depends on the path type of water course/channel, where the channel is more linearly with smallest sinuosity, like section S2, S3, S6 or S8 the distance between transversal cros section increase, and viceversa, where the river is very meandered the distance deacrease, e.g. section S1, S4, S5, S7 and S9.

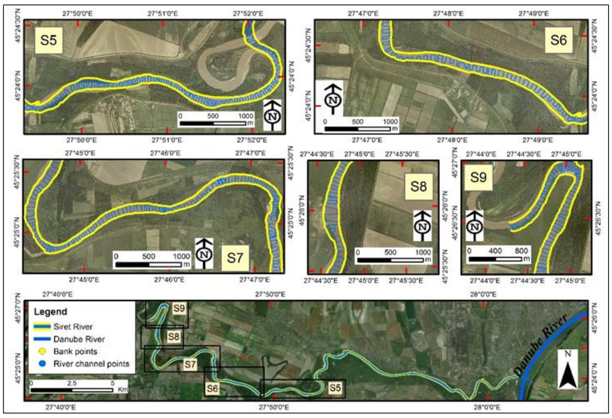


Figure 5: *Section 5-9 of depth and land surveying measurements.*

4. Results and discussion

In order to define a HEC-RAS geometric model as complex as possible, topographic measurements were performed to describe the elevation data and detailed structure of the existing bridges in the studied river section.

Thus, along the 35 km length of the river, four over-elevated structures were identified: two bridge-type structures for road purpose as seen in Fig. 6 a, b; a bridge for railway transport (Fig. 6 c) and a structure on pillars with conveyor belt destination for the Liberty Galati metallurgical unit (Fig. 6 d).

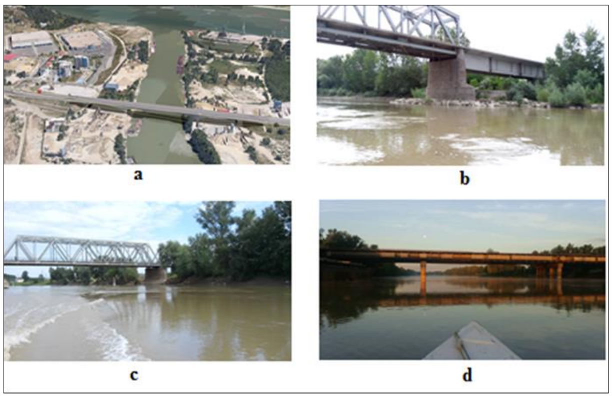


Figure 6: *Elevated structures, a – Galați-Brăila road bridge, b – Șendreni road bridge, c – Barboși railway bridge, d – Liberty conveyor belt*

Figures 7 - 10 represent the results of the elevation details of these above-mentioned elevated structures, that describe each structure on pillars, along the studied river section. Altogether, 20 pillars were identified, of which 5 pillars located in the minor riverbed and 15 in the major riverbed.

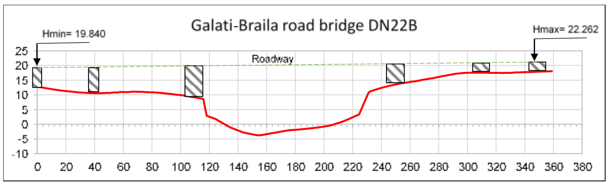


Figure 7: *Cross section profile of the DN22B road Galati - Braila (Auchan Market, km 0+0.780)*

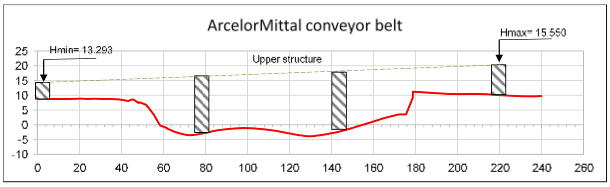


Figure 8: *Cross section profile of the Liberty conveyor belt (Liberty, km 1+0.03)*

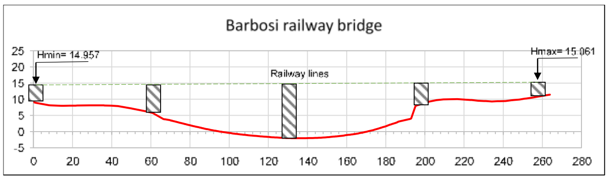


Figure 9 *Cross section profile of Barbosi railway (Barboși, km 4+0.905)*

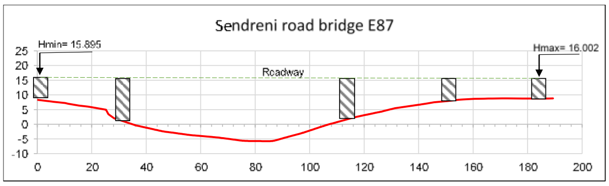
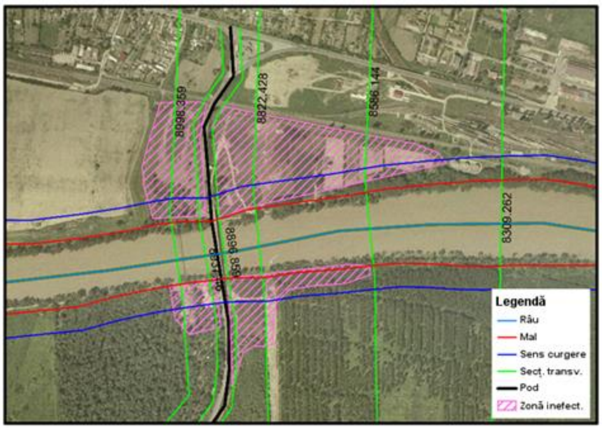


Figure 10: *Cross section profile of the Sendreni E87 road (Șendreni, km 8+0.860*

In order to determine the energy losses affected by the bridge pillars or the additional structures, the following geometrical features were digitized for each elevated structure mounted on pillars, as can be seen in Fig. 11:

- Upstream (km 8+998.359) and downstream (km 8+586.144) cross sections like cross section 4 and 1 from Fig. 1, with 4:1 length ratio from bridge.
- Upstream and downstream ineffective areas (pink boundary);
- Upstream (km 8+937.410) and downstream (km 8+896.859) cross section near the bridge or elevated structure.
- The upper part (line) of the bridge which define the maximum and minimum elevation.

Figure 11 illustrates an example of drawing the basic elements for HEC-RAS geometrical model for 1D hydraulic simulation.



- **Figure 11:** *Digitizing the basic vectors for bridge hydraulics of Sendreni roadway bridge*

Typically, according to a subcritical flow (below flood level), an ineffective or backwater area is created in which the flow depth is greater than it would be under unconstructed conditions. In the upstream part, especially at the end of the contraction reach the backwater effect is greatest. So, the flow velocity and friction loss increase with distance from this point toward the bridge.

Near the bridge construction, between sections 2 and 3 of Fig. 1 or cross section with green line in the immediate vicinity of the bridge of Fig. 11, the water surface sinks sharply, and the flow velocity reaches the maximum values. In this area the flow can be considered highly variable.

To achieve the main purpose of this study and to demonstrate the impact of expansion and contraction coefficient on water profile, it was made a hydraulic 1D simulation for the entire 35 river section. Figures 12 - 15 show the results from 1D hydraulic simulation for the water surface profile at upstream and downstream cross section of bridge. The simulation was carried out at a flow rate of 1000 m^3/s, for all 4 existing bridges. The models were executed for the compaction and expansion classes presented in Table 1.

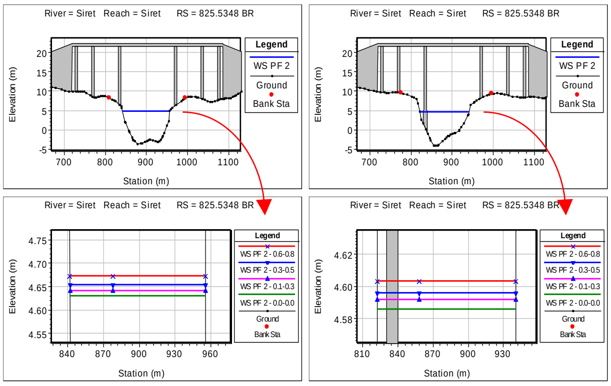


Figure 12: *Galati – Braila roadway, left side - upstream flow, right side - downstream flow*

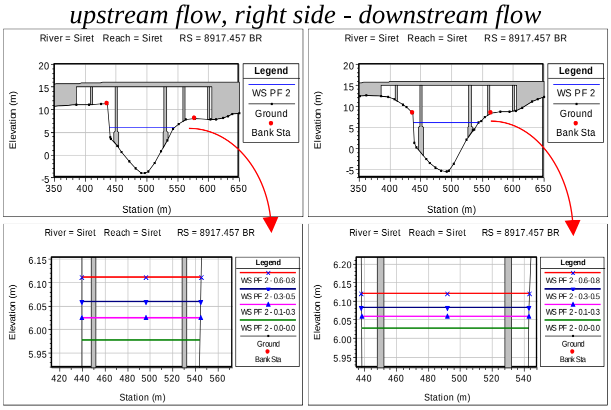


Figure 13: *Şendreni roadway bridge, left side - upstream flow, right side - downstream flow*

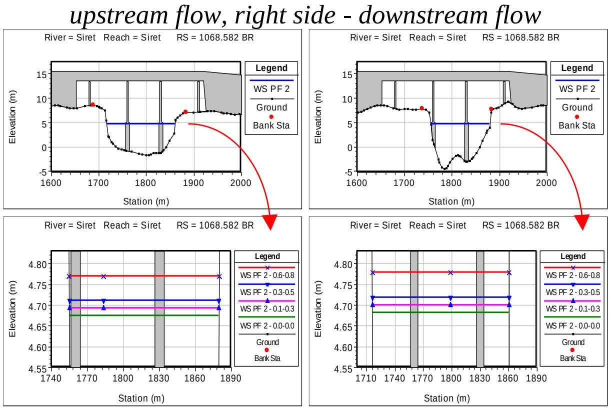


Figure 14: *Liberty conveyor belt, left side - upstream flow, right side - downstream flow*

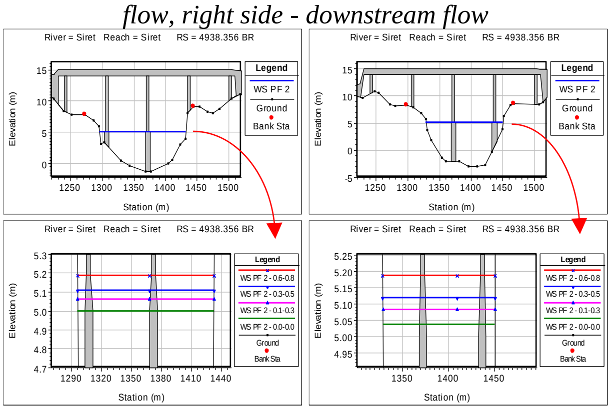


Figure 15: *Barbosi railway, left side - upstream flow, right side - downstream flow*

At first look the differences seems to be unseizable. But if the water profile represented with blue line is zoomed, it can be observed the differences. So, the differences between water profile can hit +/- 15-20 cm. In case of critical hydraulic flow these differences can conduct to a flood regime simulation.

5. Conclusions

This study was focused on demonstrating the fact that the coefficients of expansion and contraction from the vicinity of bridge areas have an important role in establishing the water surface profile. To achieve this purpose were used: an integration of bathymetric, land surveying and hydraulic simulation with GIS analysis. The result can be interpreted by separating it according to the purpose. The selection of C_c and C_e can have a high impact on water profile computations and the determination of the hydraulic jumps location. So, the increase with 0.2 units of expansion and contraction coefficients modify the water profile with 5 – 7 cm, in most of the analyzed cases. A jump is given when the coefficient is modified from class C to D, where the differences can be about 10 cm. The maximum difference is recorded for Barbosi railway, with a difference of +/- 20cm from A to D classes of coefficients.

In fact of that, an important conclusion made from this research study is that the GIS is an important system for the hydraulic simulations with potential to be accurate and cost-saving for floodplain and hazard mapping.

Acknowledgements

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