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BAHLUI RIVER RECREATION AREA ARRANGEMENT

BY

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Abstract. Bahlui River cross Iasi basically dividing the city in two. The length of water in the city is about 11 km. Following the complex work upstream, Iasi is protected from floods with probability of 1%. A sustainable development of the river for recreational and tourism is further needed. This article presents a consistent and spectacular solution for leisure and tourism development for the central area of Iasi, crossed by the Bahlui River. To achieve constructive solution works crossing, bridge hydraulic calculation method of the normative PD 95-2002 must be improved. The article proposes a method for calculating this correction.

Key words: river engineering; bridge hydraulics.

1. Introduction

The river had a total length of 119 km and an annual average flow of 2.8 m³/s. The basin area is 1967 km². Its sources are at an altitude of 500m in the vicinity of Tudora village (Botoşani County), on the eastern side of Suceava Plateau.

Between 1911 and 1913, a series of adjustments were done to the riverbed around and in Iaşi. As a result of melting snow and heavy rainfall, the Bahlui would overflow and flood the lower parts of the city, turning it into a

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marsh. There were no dams to protect against this. Documents mention great floods in 1871 and 1932.

In the '60s and '70s, more steps were taken to reduce the threat of flooding, especially concerning Dacia, Alexandru cel Bun and Mircea cel Batran neighborhoods. The investments amounted to the equivalent of 15 million dollars, as a total of 13 complex hydraulic installations were completed, as well as a series of safety dams.

In recent years, starting from 2002, Iaşi City Hall has begun to revisit the idea of turning Bahlui River navigable. This idea is part of a larger project (designed by Habitat Project) that aims to connect Bahlui River to the river Prut, effectively linking Iasi to the Black Sea. Furthermore, two ports were to be built in the county and the Prut River was to become a natural reservation. The first phase aimed to create biking and rollerblading tracks along the river, while the second proposed a regularization of the river as well as creating dams to increase the river’s depth, thus making it navigable, at least for small boats.

In November 2013, the *Amenajarea albiei râului Bahlui în municipiul Iaşi* Project was completed, which increased the carrying capacity of the riverbed. As part of that project, the following steps were taken: a de-clogging of the entire 11 km of river that runs through Iasi, bank stabilization, covering the riverbed with reinforced concrete, creating a 3.84 km long protective embankment in the Cicoarei area, repairing the protective railings, the sanitization of the entire stream as it traverses Iasi, as well as reclaiming Sesul Bahluiului through to Letcani for development

2. Hydro Technical Works

The architectural interventions done are distributed in between Podul de Piatră and Podul Tudor Vladimirescu, totaling a length of 2,438 m. In order to increase depth, a weir is proposed upstream of Podul T. Vladimirescu. The weir would be 2.20 m high (20 cm as a concrete step and 2.00 m as a mobile dam. While completely raised, the dam brings the water level at an elevation of 37.20 and creates a 2.20 m difference from upstream.

This weir allows for the accumulation of a volume of 44.000 m^3. If we’re considering minimal flow rates, water depth would be 2.20 m at the weir, 1.65 m at Podul Roş, and 0.78 m at Podul de Piatră. At minimum flow rates (4,...,6 m^3/s) the backwater causes a rise of 47 cm in water level at Podul de Piatră. At greater rates (over 45 m^3/s) this doesn’t happen as the weir will be completely lowered.

The hydro-technical installation consists of (Fig.1):

a) the air cushion driven weir;

b) the energy dissipator;

c) fish ladder to allow for longitudinal connectivity along the river;

d) hydraulic wheel, along with energy generator.

In order to constantly check the water quality, all 9 sewer spills will be fitted with sensors. The foundation for the hydro installation will be made of reinforced concrete pillars with a diameter if 1.08 m and length of 10.40 m. They will be drilled in and encased a minimum of 1m in the marl layer. On top of these pillars, a 30 m by 33.08 m, 1.50 m thick reinforced concrete foundation will be set. On top of this foundation, the rest of the elements will be placed. In front of the foundation, a pilling wall, set at the same elevation as the pillars (20.10 m), will be placed. Its length is 38.08m and it has a reinforced concrete beam at the top. The step that the weir is mounted on will be done by elevating the foundation by 20 cm above the thalweg.

Another variant that would've allowed for the trapezoidal section of the river to be preserved has been considered as well. This option included an

inflatable weir. Both options however had the 20 cm step as a component.

Fig. 1 – Wiew of hydrotechnical works.

The decision to use a mobile flap as a weir was made as it allows for superior control of water levels while also being more coherent aesthetically, especially at river flow rates above 4,...,5 m^3/s where the inflatable weir would have to be partially deflated and thus become irregular while under 75% capacity.

The flap weir option includes:

a) a coupling zone that changes the profile of the river from trapezoidal to rectangular;

b) a 2.00 m × 13.20 m steel flap including the anchoring system; the lateral walls will have heated steel sheet for the flap to glide on;

c) reinforced polyester cushion used to lower or raise the flap;
d) water level control system that uses sensors installed in the riverbed;
e) metallic pipes for compressed air;
f) air compressor.

The control system and air compressor will share the space of the wheel control room.

Characteristics:
a) flap top elevation – 37.20 m;
b) flap opening – 13.30 m;
c) step elevation – 35.20 m;
d) thalweg elevation – 35.00 m.

2.1. Hydraulic Energy Dissipator

To properly size the dissipator, the operating scenario needs to be thought out. The purpose of the weir is to create a manageable body of water upstream. As the flow increases, the flap needs to be lowered to keep the levels upstream in respectable ranges.

The elevation at top of the flap is 37.20; the berm elevation is 37.60. At 40 cm water head, the flow over the weir is 6.37 m^3/s. (overflow calculated like sharp-crested weir). When the weir is at the maximum opening at which the flow can be controlled (60º) the flow is 45.65 m^3/s. If this value is exceeded, the weir must be opened all the way.

In conclusion, the hydraulic energy that needs to be dissipated had been determined for the two extremes (maximum level and 40 cm nappe or 60º angle of gate and 1.20 m nappe). For these two position hydraulic jump is steady and difference between $h_{\text{jump}} - h_{\text{dwn}}$ = 25,...,30 cm. A basin dissipator with a depth of 44cm and length of 6.28 m has been chosen. The depth and length has been correlated with the fish ladder (Proiecte SC Proex Consult SRL Iaşi).

2.2. Fish Ladder

A vertical slits solution has been chosen for the fish ladder. Its dimensions have been determined by using the flow with 90% probability $Q_{90\%}$ = 0,12 mc/s. The ladder has 16 steps with a 14cm height difference and size of 1.50 × 1.10 m. It is made up reinforced concrete set on the foundation. The amount of energy dissipated by each step is a maximum of 200 W/m^3.

2.3. Hydraulic wheel

Considering the amount of hydraulic energy that is concentrated by this installation, a way to harness it has been proposed in the way of a hydraulic wheel. This type of wheel is has been first developed to obtain either mechanical or electric energy. Their usage has dropped at the beginning of the 20^{th} century when the modern turbine has been introduced. However, hundreds of such installations have come into service in Europe in recent years, especially in the case of small drops (a few meters), where hydraulic wheels have greater yields than Kaplan turbines (as high as 70%).

The Bahlui installation has a drop of 2m a an average flow of 2.8 m^3/s. For an installed flow of $Q_i = 1{,}6$ m^3/s we can achieve and installed power of $P_i =$ $= 20$ kW. The cumulated efficiency of the undershot wheel and generator is 60,...,65%.

The amount of energy that can be produced in a year is $E = 126$ MW.h/year in an average hydrologic year (considering the wheel works up to $Q_{80\%}$).

The wheel would be placed on the right bank to avoid pipelines of the left side. The wheel (2.5 m width and 12 m diameter) will be made of a steel frame with wood paddles. To regulate the flow, a plane flap will be fitted ahead of the wheel. The input window will have dense grating.

The generator will be placed on the wheels axis. A shared command and control center for both the wheel and the weir would be built. It will have an underground level (with the grating and wheel flap, the compressor for the weir) as well as a level above ground that houses the control systems for the installation and the water quality management system.

The parameters for the wheel will be:

Hydraulic drop	$H = 2$ m
Average flow for Bahlui	$Q_m = 2.8$ m^3/s
Installed flow	$Q_i = 1.6$ m^3/s
Wheel diameter	$D = 12$ m
Wheel width	$b = 2.50$m
Installed power	$P_i = 20$ kW

In order to make interventions on the wheel and weir an inflatable cofferdam would be placed upstream.

3. Transverse Works

Throughout the discussed sector (from Podul Tudor Vladimirescu to Podul de Piatră), the berm will be setup as pedestrian walkways. The concrete cladding of the berm will modify its roughness coefficient from that of the grass to that of concrete (from 0.03 to 0.014). The transverse stairs used for accessing the water will be removable as to not be a hindrance during floods.

The carrying capacity of the riverbed corresponds to the 5% probability flow, and is $Q_{5\%} = 87$ m^3/s for the Podul Roşu-Pod T. Vladimirescu sector and $Q_{5\%} = 113$ m^3/s for the Podul de Piatră – Podul Roşu sector. The difference is due to the two slopes the thalweg has on these sectors (0.45‰ Podul Roşu – Podul T. Vladimirescu and 0.75‰ for Podul de Piatră – Podul Roşu).

Three pedestrian bridges are proposed in the project as well as various platforms on both banks. However, all of the platforms are situated above the levels the water would reach at $Q_{1\%}$ and thus have no effect on its flow.

The influence of the bridges is discussed below.

3.1. Cable-Stayed Bridges

These bridges are placed in the Podul Roşu – Podul T. Vladimirescu sector, which has a thalweg slope of S = 0.45‰. Since the water depth is greater that the critical depth for that sector, the flow regime is slow.

Fig. 2 – Cable stayed bridge.

These bridges cause a narrowing of the riverbed. The water level for $Q_{1\%}$= 185 m^3/s needs to be calculated.

The riverbed section is trapezoidal with horizontal berms halfway through (Fig.3). The lower section has concrete cladding while the area above the berm is grassy. The water level cannot be calculated analytically, it has to be determined graphically by drawing the curve $Q = f(h)$.

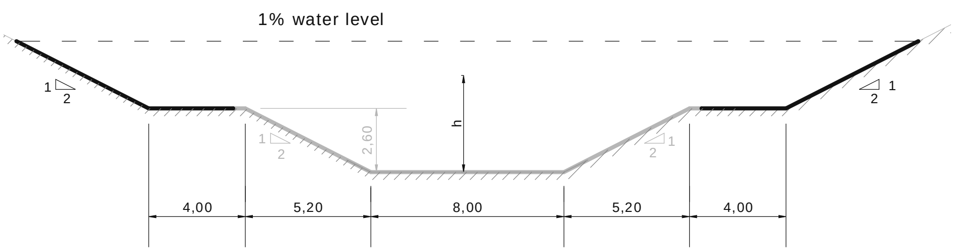

Fig. 3 – Bahlui river cross section.

Bridge span is 27.68 m

$flow: \; Q = AC\sqrt{RS}$

for h<2,60m

$A = (8+2h)h$ (section)

$P = 8 + 2h\sqrt{1+2^2} = 8 + 2h\sqrt{5}$ (wetted perimeter)

$R = \dfrac{A}{P} = \dfrac{(8+2h)h}{8+2h\sqrt{5}}$ (hydraulic radius)

for h > 2.60 m

$A = (8+2h)h + 2\cdot 4(h-2,6)$

$P = 8 + 2h\sqrt{1+2^2} + 2\cdot 4 + 2(h-2,6)\sqrt{1+2^2} = 16 + 2h\sqrt{5} + 2(h-2,6)\sqrt{5}$

$R = \dfrac{A}{P} = \dfrac{(8+2h)h + 8(h-2,6)}{16+2h\sqrt{5}+2(h-2,6)\sqrt{5}}$

Equivalent roughness coefficient n_e has been determined by

$$n_e = \left(\frac{\sum P_i n_i^{3/2}}{\sum P_i}\right)^{2/3}$$

n_1 = 0,014 for the concrete area; n_2 = 0.03 for the grassy area

The graph offers a depth of h = 4.70 m (Fig. 4).

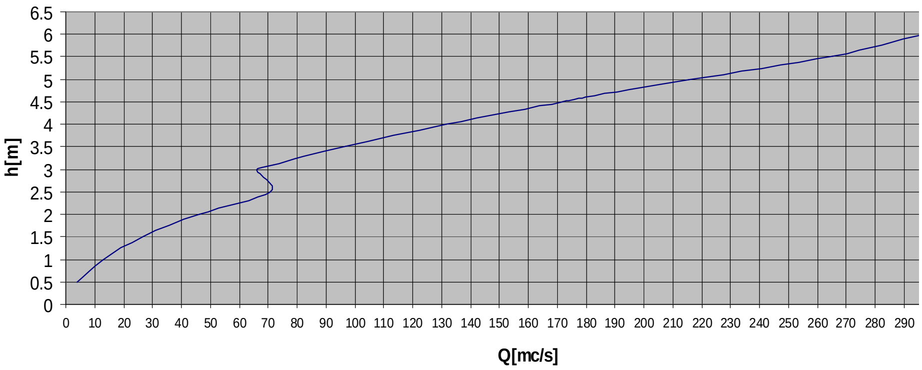

Fig. 4 – Determining water depth for $Q_{1\%}$ = 185 m^3/s ; Podul Roşu – Podul T. Vladimirescu sector.

To determine the critical depth, the following equations have been used:

$E = h + \dfrac{\alpha v^2}{2g} = h + \dfrac{\alpha Q^2}{2g\left((b+mh)h\right)^2} = h + \dfrac{\alpha Q^2}{2g\left((8+2h)h\right)^2}$ for h < 2.60 m; and

$$E = h + \frac{\alpha v^2}{2g} = h + \frac{\alpha Q^2}{2g\left((b+mh)h + 2\cdot d(h-2.6)\right)^2} = h + \qquad \text{for } h > 2.60 \text{ m.}$$
$$+ \frac{\alpha Q^2}{2g\left[(8+2h)h + 2\cdot 4(h-2.6)\right]^2}$$

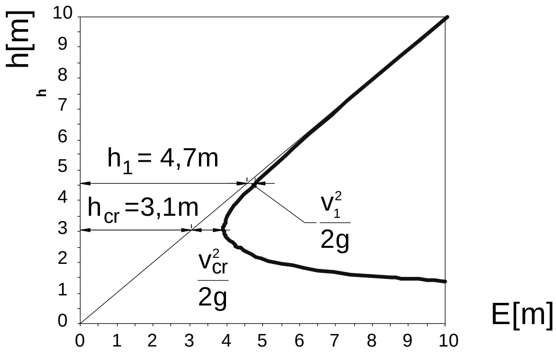

Fig. 5 – The variation of specific energy for Q = 185 m^3/s

In the current section, with a flow area of A_1 = 96.1 m^2, water speed is

$$v_1 = \frac{Q}{A_1} = \frac{185}{96.1} = 1{,}93 \text{ m/s}$$

While in the bridge area, for a flow area of A_2 =85.5 m^2, water speed is

$$v_2 = \frac{Q}{A_2} = \frac{185}{85.5} = 2.16 \text{ m/s}$$

In order for the debit to reach maximal values in the bridge area, the flow regime should be critical (Chaudhry, 2008). In the section in which the flow would be critical (A_{cr} = 48 m^2 (for $h = h_{cr}$)), the water speed would be

$$v_{cr} = \frac{Q}{A_{cr}} = \frac{185}{48} = 3.85 \text{ m/s.}$$

The graph (Fig. 6) tells us that for a flow of 185 m^3/s we have h = = 4.55 m.

With this data, we have the specific energies for both section:

$$E_1 = h + \frac{\alpha v_1^2}{2g} = 4.7 + \frac{1.1\times 1.93^2}{2\times 9.81} = 4.9 \text{ m (upstream)}$$

$$E_2 = h_2 + \frac{\alpha v_2^2}{2g} = 4.55 + \frac{1.1\times 2.16^2}{2\times 9.81} = 4.8 \text{ m (bridge section).}$$

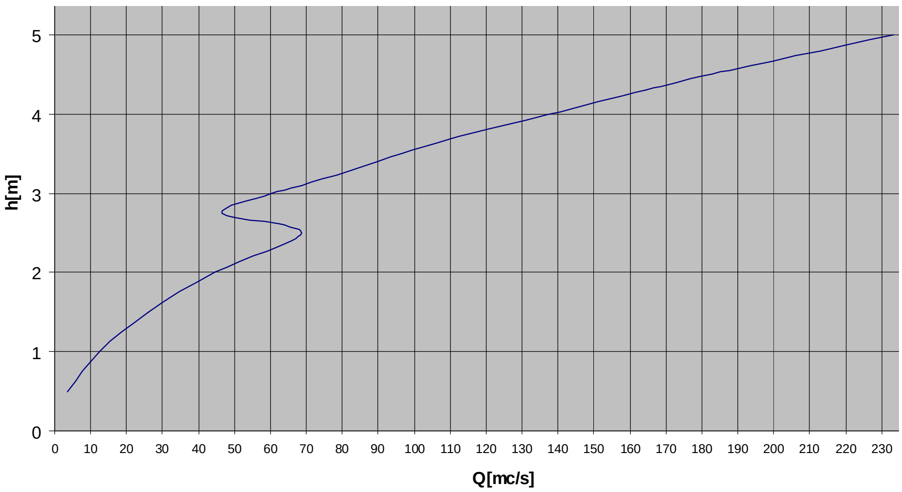

Fig. 6 – Debit curve in the cable stayed bridge section.

If flow regime it will be critical the water energy upstream bridge will be:

$$E_c = h_{cr} + \frac{\alpha v_{cr}^2}{2g} = 3.1 + \frac{1.1\times 3.85^2}{2\times 9.81} = 3.93 \text{ m,}$$

$E_c<E_1$ so bridge lateral contraction do not produce bakwater but drop-down curve

4. Conclusions

The PD 95-2002 standard regarding hydraulic design of bridges, (article 33a) states that a backwater effect is appears upstream of a bridge caused by the narrowing of the flow section. That difference is:

$$\Delta z = \frac{v_{mp}^2 - v_m^2}{2g};$$

in which: v_m average water speed upstream; v_{mp} average water speed in the bridge section.

In reality, a slow flow regime causes a decrease in water levels if the narrowing is within certain limits. The flow section can be reduced until a critical flow regime is generated without seeing an increase in water levels.

If the flow regime is fast ($h < h_{cr}$; $v > v_{cr}$), then a narrowing causes a rise in levels upstream.

In conclusion, the PD 95 – 2002 standard needs further specifications in order to be taken intro consideration when looking at the phenomenon that takes place in the river.

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AMENAJARE PENTRU AGREMENT A RÂULUI BAHLUI

(Rezumat)

Râul Bahlui traversează oraşul Iaşi impărțind practic oraşul în două. Lungimea cursului de apa pe teritoriul oraşului este de circa 11 km. In urma lucrărilor complexe realizate in amonte, oraşul Iaşi este protejat la viituri cu probabilitatea de apariție de 1%. În continuare este necesar sa fie amenajat cursul de apă pentru necesități de agrement şi turistice. Articolul prezintă o soluție coerentă şi spectaculoasă de dezvoltare pentru agrement şi turism a zonei centrale a Iaşului, traversată de râul Bahlui. Pentru a realiza soluția constructivă a lucrărilor de traversare, metoda de calculul hidraulic a podurilor din normativul PD 95 – 2002 trebuie să fie imbunătățită. În articol se propune această corecție a metodei de calcul.