WARSAW UNIVERSITY OF TECHNOLOGY Index 351733
FACULTY OF CIVIL ENGINEERING
COMMITTEE FOR CIVIL AND WATER ENGINEERING
POLISH ACADEMY OF SCIENCES ISSN 1230-2945
DOI: 10.24425/ace.2022.140185
ARCHIVES OF CIVIL ENGINEERING
Vol. LXVIII ISSUE 1 2022

pp. 555 –568

Research paper

The application of a minimum specific energy concept for a fish ladder design

Michał Kubrak[1], Błażej Smoliński[2], Jaromír Riha[3], Apoloniusz Kodura[4], Paweł Popielski[5], Kamil Jabłoński[6]

Abstract: Structural solutions in terms of fish ladders and the use of natural materials to construct them often raise concerns regarding the possibility of using the standard calculation methods. The fish ladder being designed on the Wisłok river consists of three pools, separated from each other by baffles made of rock boulders. The purpose of this study was to analyze water surface profiles for fish ladder at specific values of flow rates. The paper presents the results of hydraulic calculations under the conditions of constant flow rate based on the concept of a minimum specific energy. According to this method, water flow through boulders is critical. Thus, it does not take into account head losses, which are hard to estimate and which are the integral part of typical calculation methods, e.g. the use of equations to determine the flow rate of a weir. An additional advantage of this method is that there is no need to assume the flow pattern of one specific weir. Verification calculations of the water depths were conducted using the HEC–RAS software, under an assumption of an one-dimensional steady water flow. Water depths in the fish ladder, calculated using both methods, were similar, despite the adopted different calculation concepts, and can be used in ichthyologic analyses.

Keywords: fish ladder, dam, specific energy, critical flow

---

[1] PhD., Eng., Warsaw University of Technology, Faculty of Building Services, Hydro and Environmental Engineering, ul. Nowowiejska 20, 00-653 Warsaw, Poland, e-mail: michal.kubrak@pw.edu.pl, ORCID: 0000-0001-8097-3803

[2] PhD., Eng., Warsaw University of Technology, Faculty of Building Services, Hydro and Environmental Engineering, ul. Nowowiejska 20, 00-653 Warsaw, Poland, e-mail: blazej.smolinski@pw.edu.pl, ORCID: 0000-0003-3662-2007

[3] Prof., DSc., PhD, Eng., Brno University of Technology, Faculty of Civil Engineering, Veveří 331/95, 602 00 Brno, Czech Republic, e-mail: riha.j@fce.vutbr.cz, ORCID: 0000-0002-1362-5769

[4] DSc., PhD., Eng., Warsaw University of Technology, Faculty of Building Services, Hydro and Environmental Engineering, ul. Nowowiejska 20, 00-653 Warsaw, Poland, e-mail: apoloniusz.kodura@pw.edu.pl, ORCID: 0000-0001-7040-1625

[5] DSc., PhD., Eng., Warsaw University of Technology, Faculty of Building Services, Hydro and Environmental Engineering, ul. Nowowiejska 20, 00-653 Warsaw, Poland, e-mail: pawel.popielski@pw.edu.pl, ORCID: 0000-0002-5425-5821

[6] M.Sc., Eng., Energoprojekt-Warszawa SA, Al. Niepodległości 58, 02-626 Warsaw, Poland, e-mail: kjablonski@energoprojekt.pl

1. Introduction

Fish ladders enable the migration of fish and other aquatic organisms through structures partitioning a riverbed. Therefore, fish ladders are a key element in improving the ecological state of flowing waters [1].

Two fish ladder types can be distinguished – purely technological devices (pool and slot fish ladders, fish locks, fish lifts) and ones that imitate the natural environment (bypass channels, bed ramps). Regardless of the fish ladder type, it is crucial to check the values of hydraulic parameters (water depth and flow velocities) and refer them to the values that should correspond to an effective fish pass. Evaluating fish ladders in terms of satisfying appropriate ichthyological requirements is significantly challenging, both when engineering new ones and analysing already operating devices. [2] demonstrated that existing fish ladders often do not function correctly.

Measuring and determining the aforementioned hydraulic parameters of fish ladders is the subject of numerous measurements, both in the field [3], [4], as well as on a laboratory scale [5, 6]. Software use also plays an important role in analysing the hydraulic flow rate parameters in fish ladders. Such CFD software as FLOW 3D [7, 8], DualSPHysics [9] and programmes for hydraulic computations in open channels (HEC–RAS) are used for this purpose [10].

The objective of this study was to calculate the water table elevations in the planned fish ladder on the Wisłok river at selected values of discharge. The depths, at known discharge in fish ladder pools were calculated based on an assumed minimum specific energy in the section with large-size boulders. The suggested method enabled to simply estimate water depths in the planned fish ladder which allows to calculate values of water flow velocity. Thus-calculated water depths were compared to the depths calculated using the HEC–RAS software for a one-dimensional steady flow.

2. Characteristics of the designed fish ladder

The Wisłok riverbed, in the cross-section of the designed fish ladder, is horizontal and has a width of 35 m. Across the width of a river, a 1.30 m high fixed-crest dam is located. Water flowing over the top of the fixed-crest dam is passed into a reinforced concrete drop structure, in which hydraulic jump is formed, and then water flows with a subcritical flow. The designed fish ladder is to be located at 58.500 km of the Wisłok river. The fish ladder imitating natural habitat and hydraulic conditions characteristic of the Wisłok waters was designed in the form of a cascading rapids stretching along the entire riverbed width. The fish ladder was to consists of four rows of boulders, forming three pools located downstream of the weir. The pools were separated with baffles made of four rows of $1.0\div1.5$ m high rock boulders. Each baffle was equipped with fish migration slots of varied width and spacing. The designed solution is shown in Figs. 1 and 2.

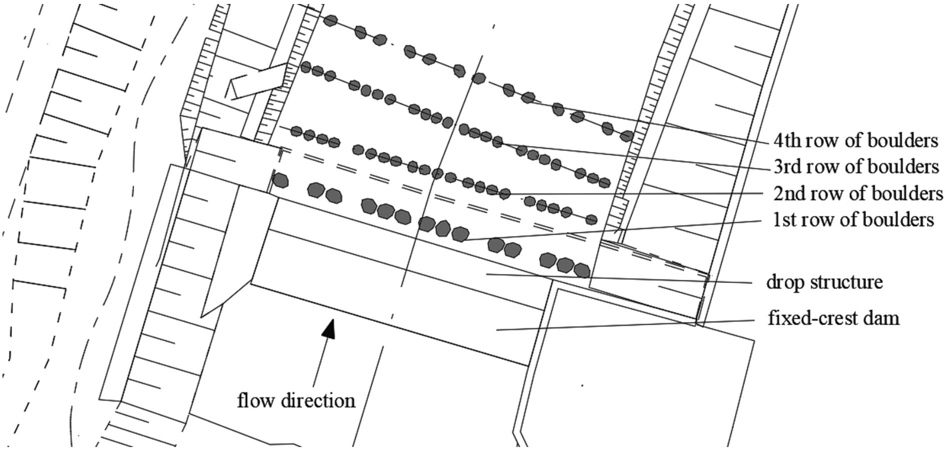

Fig. 1. Diagram of the designed fish ladder – top view

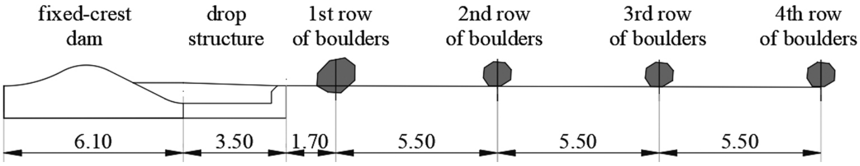

Fig. 2. Diagram of the designed fish ladder – longitudinal section along the axis

Introducing boulders into the riverbed (Fig. 2) will cause damming up and change the water flow conditions. Rock heights, their number and slot widths for each boulder row are shown in Table 1.

Table 1. Dimensions of boulders in individual rows

Boulder row	Boulder height p [m]	Number of slots n [–]	Slot width B [m]
1st	1.5	7	1.0
2nd	1.0	6	1.0
3rd	1.0	5	1.6
4th	1.0	6	2.2

According to the information in an ichthyological expertise [11] developed for the purposes of the fish ladder being designed, it should satisfy the following requirements regarding the minimum depths in individual pools, at a discharge of $Q = 2.72$ m^3/s for individual fish species: 0.4 m for brown trout, 0.45 m for grayling, chub, roach and dace, 0.5 m for barbel, bream, perch, pike, salmon and sea trout and 0.8÷1.0 m for sturgeon.

3. Hydraulic calculations

Water flow depths were calculated for two variants of different flow patterns. In the first variant, the discharge is so low that the water flows through the slots between the boulders. Whereas in the second case, at higher values of discharge, water flows through the slots and over the boulder crest. In the calculations, a rectangular shape of boulders and slots was assumed. It should be noted, that the exact shape of the boulders is not known. During the design process, only height of boulders was assumed. The calculations were conducted based on the concept of a minimum specific energy [12]. According to this method, water flows for given discharge through the slots, with a minimum energy (the flow is critical). Thus, it does not take into account head losses, which are hard to estimate and which are the integral part of typical calculation methods, e.g. the use of equations to determine the flow rate of a weir. The local losses, such as those in a flow over boulders, occur in short length of the channel. In such short lengths, the losses due to shear at the boundaries are very small and can be neglected. An additional advantage of this method is that there is no need to assume the flow pattern of one specific weir. The use of minimum specific energy concept provides conceptual simplicity, however this method has some limitations. It is not suitable if the flow through the slots or over the boulders is submerged.

The calculations were conducted for 5 different values of discharge (2.72 m^3/s, 4.10 m^3/s, 10.70 m^3/s, 16.86 m^3/s and 32.80 m^3/s), for which water depths at specific cross-sections were earlier measured in the riverbed without the boulders. Depth values calculated using the HEC–RAS software, under the assumption of 1D steady flow were used to verify calculated water depths in pools.

3.1. I Variant of flow pattern – flow in the slots

At low values of discharge, water in the fish ladder will overcome rows of boulders flowing through the slots between such rows. The discharge for one slot is equal to:

$$Q = \frac{Q_t}{n} \tag{3.1}$$

where: Q – discharge in a single slot, Q_t – total discharge, n – number of slots for a given row of boulders.

It was assumed, that the water flows through the slots with a minimum specific energy. The general equation for critical flow is [13]:

$$\frac{A^3}{B} = \frac{\alpha Q^2}{g} \tag{3.2}$$

where: A – cross-sectional area of the water stream for critical flow conditions, B – slot width, α – Saint–Venant coefficient (it was assumed that $\alpha = 1$).

Water depth in a single slot was calculated using the critical flow equation (3.2) – Fig. 3.

Therefore, water depth in a single slot is a critical depth – Fig. 4.

The critical depth location presented in Fig. 4 requires additional comment. In order to keep critical depth across the boulder slots, the boulder's crest should be of sufficient length

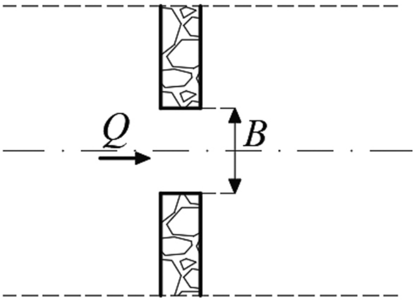

Fig. 3. Scheme of I variant of flow pattern – top view

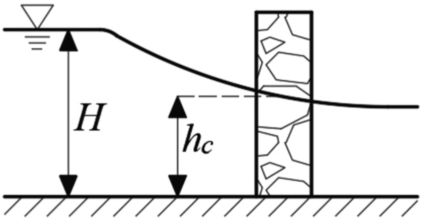

Fig. 4. Scheme of I variant of flow pattern ($v0$) – cross-section

(as in broad-crested weirs). In fact, the exact location of the critical depth is unknown and can't be determined analytically. However, in the presented method, the unsubmerged water flow is assumed and the location of the critical depth does not influence the value of water depth H. In a cross-sectional bed, the critical depth h_c is calculated from the equation (3.2) rearranged into:

$$h_c = \sqrt[3]{\frac{\alpha Q^2}{g B^2}} \tag{3.3}$$

At critical flow, the depth is equal to twice the kinetic energy head and therefore two-thirds of the critical specific energy. Neglecting the velocity head ($v \approx 0$), it can be assumed that water depth upstream of a given row of boulders H is approximately equal to:

$$H = \frac{3}{2} h_c \tag{3.4}$$

The aforementioned method was used to estimate water depth upstream of each row of boulders. The critical depth, previously calculated from relationship (3.3) is the water depth in the slot, at known water flow rate.

3.2. II Variant of flow pattern – flow between the slots and over the boulders

When the water depth upstream of the boulders, calculated from the equation (3.4) is higher than the boulder height, water flows not only through the slots but also over the boulder crest. A scheme of water flow in the II variant is presented in Fig. 5.

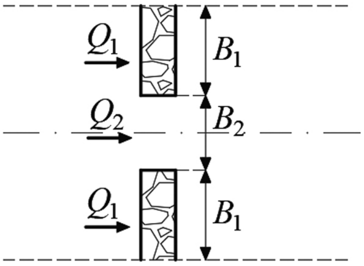

Fig. 5. Scheme of II variant of flow pattern – top view

Total discharge through the fish ladder is the sum of discharge in $n+1$ rows of boulders Q_1 and in n slots Q_2:

(3.5)
$$Q_t = (n+1)Q_1 + nQ_2$$

Critical water flow occurs in the slots and over the boulders – Fig. 6.

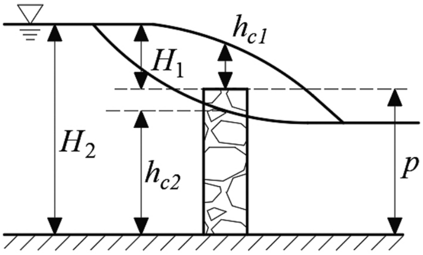

Fig. 6. Scheme of II variant of flow pattern ($v \approx 0$) – cross-section

As in the case of variant I, assuming that the flow is unsubmerged, the exact location of the critical depth is unknown and it does not affect the calculated value of H_1. By transforming the critical flow equation (3.2) to calculate Q_1 and Q_2, one obtains:

(3.6)
$$Q_1 = \sqrt{\frac{g}{\alpha}\frac{A_1^3}{B_1}}$$

where: A_1 – cross-sectional area of the water stream flowing over boulders in $n+1$ sections, B_1 – water table width for the stream of water flowing over the boulders and:

(3.7)
$$Q_2 = \sqrt{\frac{g}{\alpha}\frac{A_2^3}{B_2}}$$

where: A_2 – cross-sectional area of the water stream flowing between n slots, B_2 – water table width for the stream of water flowing between the slots.

$$A_1 = h_{c1} B_1 \tag{3.8}$$

$$A_2 = h_{c2} B_2 \tag{3.9}$$

Depth H_1 is related to boulder crests, while H_2 to pool bottom:

$$H_1 = \frac{3}{2} h_{c1} \tag{3.10}$$

$$H_2 = \frac{3}{2} h_{c2} \tag{3.11}$$

i.e.:

$$H_2 = p + H_1 \tag{3.12}$$

where: p – boulder height.

Then, the total discharge through the fish ladder is equal to:

$$Q_t = (n+1)\sqrt{\frac{g}{\alpha}\frac{\left[\frac{2}{3}\left(H_2 - p\right)B_1\right]^3}{B_1}} + n\sqrt{\frac{g}{\alpha}\frac{\left(\frac{2}{3}H_2 B_2\right)^3}{B_2}} \tag{3.13}$$

The calculations, due to the implicit form of equation (3.13) were conducted using the method of successive approximations. Water depth upstream of the boulders H_2 was calculated for a known value of discharge Q_t using equation (3.13), followed by calculating water depth in the slot based on equation (3.11).

3.3. Water depth calculation results

The water depths calculated using the described method are presented in Table 2. H denotes water depths upstream of a given row of boulders, while h – water depths in the slot.

Table 2. Calculated values of water depths

Q [m^3/s]	1st boulder row		2nd boulder row		3rd boulder row		4th boulder row	
	H [m]	h [m]	H [m]	h [m]	H [m]	h [m]	H [m]	h [m]
2.72	$\underline{0.37}$	0.25	0.41	0.28	0.34	0.23	0.24	0.16
4.10	$\underline{0.49}$	0.33	0.54	0.36	0.45	0.30	0.32	0.21
10.70	$\underline{0.93}$	0.62	1.02	0.68	0.85	0.57	0.61	0.41
16.86	1.26	0.84	1.17	0.78	1.09	0.72	0.82	0.55
32.80	1.71	1.14	1.42	0.95	1.35	0.90	1.19	0.79

Table 2 underlines depth values for which water depth upstream of the first row of boulders, calculated using the described method, was lower than the depth upstream of the second row. Such calculation results show that for flow rates of: 2.72 m^3/s, 4.10 m^3/s and 10.70 m^3/s, the assumption on the critical water flow in slots within the first boulder row was incorrect and leads to non-physical results.

The first row of boulders has a decisive influence on water damming for greater flow rates (16.86 m^3/s and 32.80 m^3/s). The fact that the first row of boulders is higher than the other ones is of additional significance.

3.4. Hydraulic jump downstream the weir

Hydraulic jump may be formed in a fish ladder pool downstream of a fixed-crest dam. For this reason, basic hydraulic jump parameters were calculated, i.e., its conjugate depths and length. The conjugate depth upstream of hydraulic jump h_1 was calculated using the energy equation:

$$h_1^3 - E_0 h_1^2 + \frac{\alpha v_1^2}{2g} = 0 \tag{3.14}$$

where: h_1 – conjugate depth upstream of the hydraulic jump, E_0 – energy upstream of the weir, v_1 – water flow velocity within the section of the conjugate depth upstream of the hydraulic jump.

The conjugate depth downstream of the hydraulic jump h_2 was calculated from:

$$h_2 = -\frac{h_1}{2} + \sqrt{\frac{h_1^2}{4} + \frac{2v_1^2 h_1}{g}} \tag{3.15}$$

Hydraulic jump length L was estimated using the Wójcicki empirical formula [14]:

$$L = \left(8 - 0.05\frac{h_2}{h_1}\right)(h_2 - h_1) \tag{3.16}$$

The calculations were conducted for discharges at known water depth upstream of the fixed-crest dam, i.e., for: 16.86 m^3/s and 32.8 m^3/s. For a discharge of 2.72 m^3/s, the hydraulic jump does not form in the first pool. In each of the cases, the conjugate depth downstream of the hydraulic jump calculated for the aforementioned values of discharge was significantly lower than the water depth upstream of the boulders calculated previously. The length of hydraulic jump was shorter than the distance of the first boulder row from the fixed-crest dam. This means that the hydraulic jump will not affect the water depth in individual fish ladder pools.

4. HEC–RAS software computations

The verification computations were conducted using the HEC–RAS software [15]. It enables calculating a steady, 1D water flow and is widely used in engineering practice.

The first stage of HEC–RAS computations involved modelling the current riverbed condition, i.e., taking into account measured bathymetric sections with their locations and the existing fixed-crest dam (58.500 km) with a crest elevation of 190.50 m a.s.l. The fixed-crest dam was modelled as an “Inline Structure”, which is an element dedicated to such applications. This model did not include boulders in the river bed (Fig. 7).

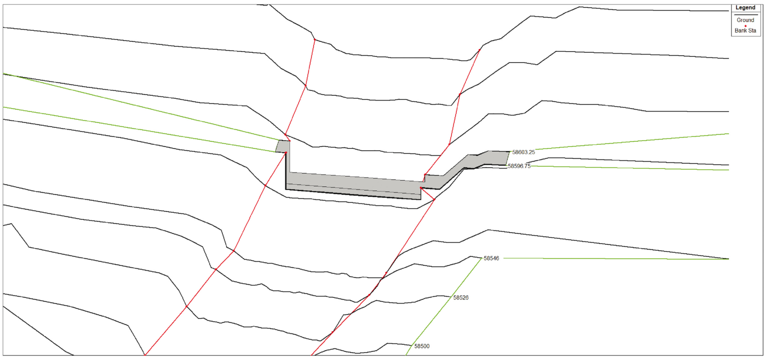

Fig. 7. Computational model of existing river bed generated in HEC–RAS

Calibration of computational model was done by adjusting values of the roughness coefficient, in order to obtain the result of calculation that match the results of hydrological measurements. The calibration was conducted for a measured discharge of $Q = 32.80$ m^3/s and corresponding measured water table elevations. The differences between measured water table elevations and the HEC–RAS computation results do not exceed 0.07 m. A comparison of the calculated and measured water table profile in the riverbed without the fish pass is shown in Fig. 8.

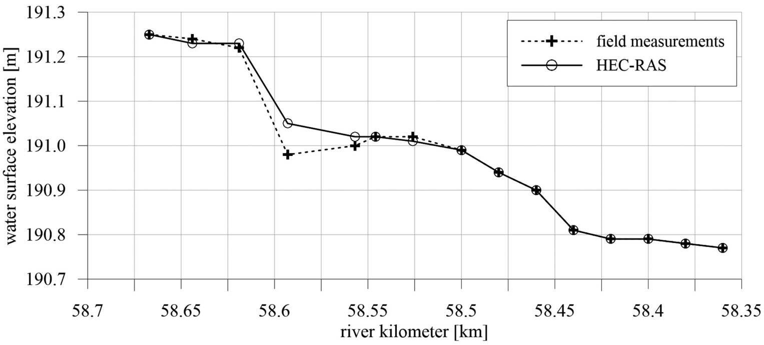

Fig. 8. Calculated and measured water surface profile

The second stage of the calculations included the new elevation of the fixed-crest dam (190.60 m a.s.l.) and the fish ladder structure with resulting bed geometry and boulder arrangement (Fig. 9).

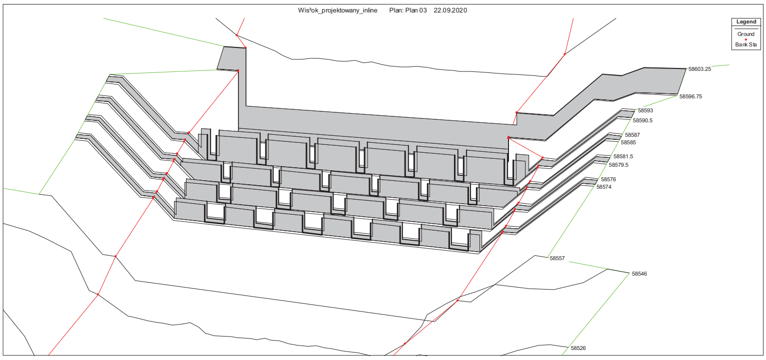

Fig. 9. Calculated and measured water surface profile

The rows of boulders forming fish ladder pools were modelled in a similar way, additionally taking into account the location and dimension of migration slots. The “Gates” option was used for this purpose. The default value of weir coefficient equal to 1.67 was used as an input. Water table elevation calculations were conducted under the conditions of steady flow. Values of discharge and water table elevations at the lowest cross-section were set as boundary conditions. The water table profile was calculated for 5 values of discharge, equal to 2.72 m^3/s; 4.10 m^3/s, 10.70 m^3/s, 16.86 m^3/s and 32.80 m^3/s. The calculated water surface profiles are presented in Fig. 10.

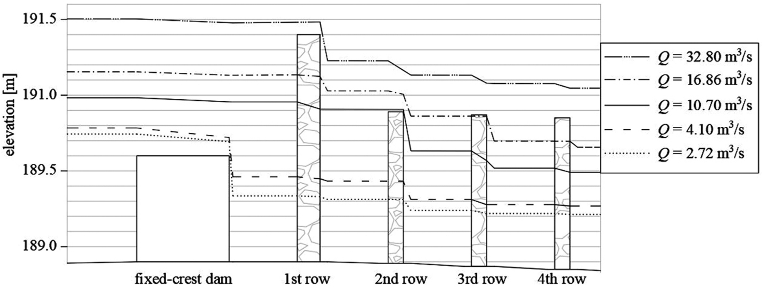

Fig. 10. Water table profiles calculated using the HEC–RAS software

5. Comparison of calculation results

The water depths calculated on the basis of an assumed minimum specific energy concept, at a given discharge were compared with water depths calculated using the HEC–RAS software (Table 3). The H_{SE} symbol denotes analytically calculated depths upstream of the boulders, while H_{HR} denotes the results of HEC–RAS computations.

The water depths upstream of the boulders, calculated using two methods, are similar, and the standard deviation is 8%. The calculation results for both methods are compared

Table 3. List of calculated water depths

Q [m^3/s]	1st boulder row		2nd boulder row		3rd boulder row		4th boulder row	
	H_{SE} [m]	H_{HR} [m]	H_{SE} [m]	H_{HR} [m]	H_{SE} [m]	H_{HR} [m]	H_{SE} [m]	H_{HR} [m]
2.72	–	0.44	0.41	0.40	0.34	0.36	0.24	0.36
4.10	–	0.56	0.54	0.53	0.45	0.42	0.32	0.42
10.70	–	1.06	1.02	1.01	0.85	0.75	0.61	0.66
16.86	1.26	1.23	1.17	1.11	1.09	0.99	0.82	0.85
32.80	1.71	1.60	1.42	1.35	1.35	1.28	1.19	1.24

in Figs. 11–15. Dotted line represents water depths calculated with a minimum specific energy method (m.s.e. method) and dashed line corresponds to water depths calculated with HEC–RAS.

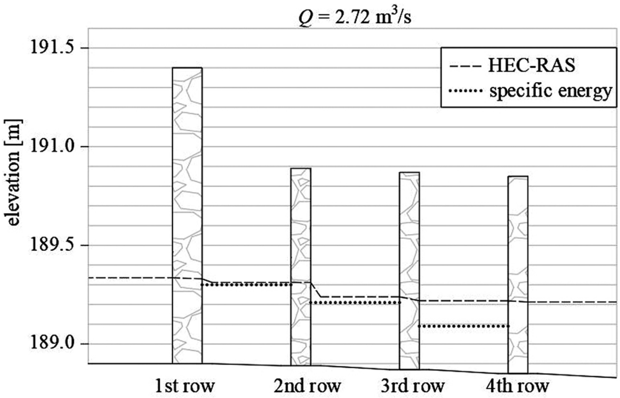

Fig. 11. Comparison of calculated water table elevations for a discharge of $Q = 2.72$ m^3/s

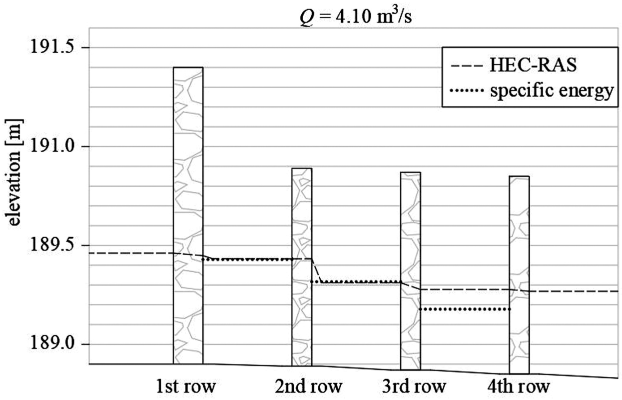

Fig. 12. Comparison of calculated water table elevations for a discharge of $Q = 4.10$ m^3/s

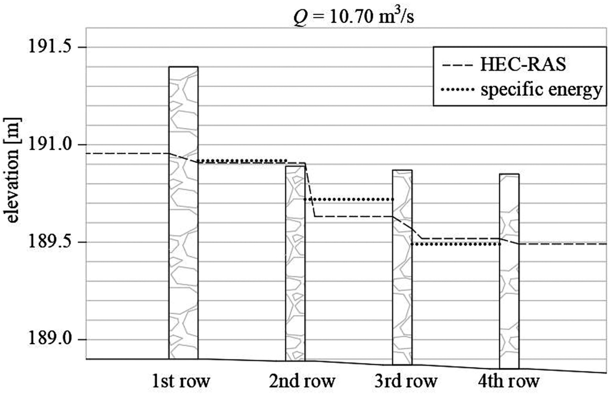

Fig. 13. Comparison of calculated water table elevations for a discharge of Q = 10.70 m^3/s

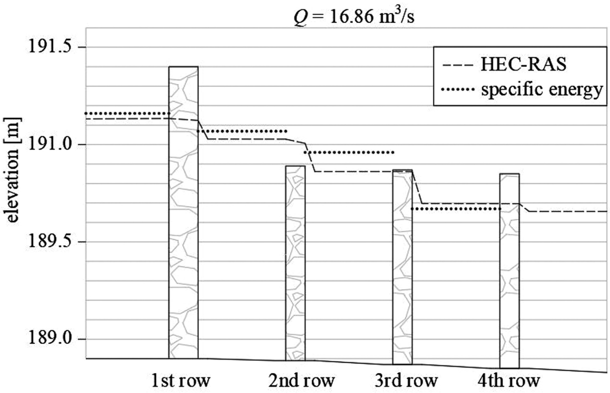

Fig. 14. Comparison of calculated water table elevations for a discharge of Q = 16.86 m^3/s

Figs. 11, 12 and 13 do not take into account the water depth upstream of the first row of boulders calculated based on a minimum specific energy method, since they are lower than in the fish pass upstream of the second boulder row. These depths do not correspond to physical flow rate conditions. This also means, that in the case discharges lower than 10.7 m^3/s, there is no critical water flow in the slots of the first boulder row. Therefore, the assumption regarding the minimum specific energy, at flow rates below 10.7 m^3/s is not suitable. With flow rates of 16.86 m^3/s and higher, the adopted assumption is justified (Figs. 13, 14).

The calculated water depths in pools with a discharge of 2.72 m^3/s do not exceed 0.46 m and fail to satisfy the requirements regarding the minimum water depth in individual pools, associated with ensuring optimum conditions for the migration of fish with high species diversity. As stipulated in [11] the minimum depth in pools for this discharge should be 0.8 ÷ 1.0 m. These conditions occur in all pools at values of discharge higher than 16.86 m^3/s.

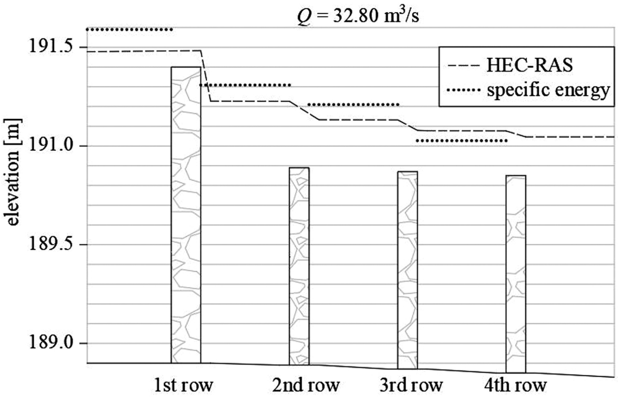

Fig. 15. Comparison of calculated water table elevations for a discharge of $Q = 32.80$ m^3/s

6. Summary and conclusions

The conducted calculations enable drawing two main conclusions that relate both to the applied calculation methodology and the hydraulic conditions within the designed fish ladder. The described engineering method is based on an assumed minimum specific energy concept in the individual fish ladder sections. It enables a simple determination of the water depths in fish ladder pools. However, this method has its limitations. It requires an in-depth analysis of each section depth calculation results, in order to exclude solutions that do not satisfy the critical water flow conditions. Also, it is not suitable if the flow through the slots or over the boulders is submerged. Nonetheless, it can be used for calculating the water depths in the designed fish ladder pools in case where local head losses are hard to estimate.

The calculated water depths at lowest flow rates do not exceed 0.46 m and are lower than the recommended 0.8 ÷ 1.0 m. For this reason, the analyzed fish ladder structure, created by building-up a river bed section with boulders, does not meet the requirements for the migration of fish with high species diversity.

References

[1] P. Nawrocki, P. Kupczyk-Kuriata, Fundacja WWF Polska, and Food and Agriculture Organization of the United Nations, Eds., *Przepławki dla ryb: projektowanie, wymiary, monitoring*. Warszawa: Fundacja WWF Polska, 2016.

[2] X. Mao, “Review of fishway research in China”, *Ecological Engineering*, 2018, vol. 115, pp. 91–95, DOI: 10.1016/j.ecoleng.2018.01.010.

[3] M. Bombač, M. Četina, G. Novak, “Study on flow characteristics in vertical slot fishways regarding slot layout optimization”, *Ecological Engineering*, 2017, vol. 107, pp. 126–136, DOI: 10.1016/j.ecoleng.2017.07.008.

[4] B.A. Marriner, A.B. M. Baki, D.Z. Zhu, S.J. Cooke, C. Katopodis, “The hydraulics of a vertical slot fishway: A case study on the multi-species Vianney-Legendre fishway in Quebec, Canada”, *Ecological Engineering*, 2016, vol. 90, pp. 190–202, DOI: 10.1016/j.ecoleng.2016.01.032.

[5] J. Puertas, L. Pena, T. Teijeiro, "Experimental Approach to the Hydraulics of Vertical Slot Fishways", *Journal of Hydraulic Engineering*, 2004, vol. 130, no. 1, pp. 10–23, DOI: 10.1061/(ASCE)0733-9429(2004)130:1(10).

[6] L. Tarrade, A. Texier, L. David, M. Larinier, "Topologies and measurements of turbulent flow in vertical slot fishways", *Hydrobiologia*, 2008, vol. 609, no. 1, pp. 177–188, DOI: 10.1007/s10750-008-9416-y.

[7] S. M. A. Abdelaziz, Numerical simulation of fish behavior and fish movement through passages. München: Lehrstuhl und Versuchsanst. für Wasserbau und Wasserwirtschaft der Technischen Univ. München, 2013.

[8] J.M. Duguay, R.W.J. Lacey, J. Gaucher, "A case study of a pool and weir fishway modeled with OpenFOAM and FLOW-3D", *Ecological Engineering*, 2017, vol. 103, pp. 31–42, DOI: 10.1016/j.ecoleng.2017.01.042.

[9] G. Novak, A. Tafuni, J.M. Domínguez, M. Četina, D. Žagar, "A Numerical Study of Fluid Flow in a Vertical Slot Fishway with the Smoothed Particle Hydrodynamics Method", *Water*, 2019, vol. 11, no. 9, DOI: 10.3390/w11091928.

[10] M. Hammerling, N. Walczak, Z. Walczak, P. Zawadzki, "The possibilities of using HEC–RAS software for modelling hydraulic conditions of water flow in the fish pass exampled by the Pomiłowo barrage on the Wieprza river", *Journal of Ecological Engineering*, 2016, vol. 17, no. 2, pp. 81–89, DOI: 10.12911/22998993/62294.

[11] Ł. Cieślik, I. Cieślik, "Opinia ichtiologiczna dla przedsięwzięcia 'Odtworzenie progu piętrzącego na rzece Wisłok – remont kapitalny progu piętrzącego i umocnień dna brzegów rzeki powyżej i poniżej progu oraz budowa przepławki dla ryb', EKO-KONSULT Łukasz Cieślik" (in polish), 2020.

[12] M.H. Chaudhry, *Open-channel flow.* 2ed. New York, NY: Springer, 2008.

[13] R.H.J. Sellin, *Flow in channels*. London, New York: Macmillan; St. Martin's P, 1969.

[14] M. Mitosek, *Mechanika płynów w inżynierii i ochronie środowiska*. Warszawa: Oficyna Wydawnicza Politechniki Warszawskiej, 2020.

[15] G.W. Brunner, HEC–RAS river analysis system: hydraulic reference manual. Davis, CA: US Army Corps of Engineers, Institute for Water Resources, Hydrologic Engineering Center, 2010.

Wykorzystanie zasady minimalnej energii własnej strumienia wody do obliczeń przepławek dla ryb

Słowa kluczowe: przepławka, zapora, ruch krytyczny, głębokość krytyczna

Streszczenie:

Rozwiązania konstrukcyjne przepławek i wykorzystywanie do ich budowy naturalnych materiałów budzą często obawy o możliwości stosowania do ich obliczeń typowych schematów hydraulicznych. Projektowana przepławka na rzece Wisłok składa się z trzech komór, oddzielonych od siebie przegrodami z kamiennych głazów. Celem obliczeń było określenie profilu zwierciadła wody w przepławce przy wybranych wartościach natężeń przepływu wody. Przedstawiono wyniki obliczeń hydraulicznych przepławki przeprowadzone w warunkach stałego natężenia przepływu w oparciu o zasadę minimalnej energii własnej strumienia wody. Według tej metody woda przepływa przez szczeliny lub przelewa się nad głazami przy minimalnym nakładzie energii (przepływ odbywa się ruchem krytycznym). W obliczeniach założono, że głazy są prostopadłościanami, a przekroje poprzeczne szczelin mają kształt prostokąta. Obliczenia weryfikacyjne głębokości wody przeprowadzono programem HEC–RAS w założeniu występowania ruchu ustalonego wody. Obliczone obiema metodami głębokości wody w przepławce są zbliżone, mimo przyjętych różnych koncepcji obliczeń i mogą być wykorzystane w analizach ichtiologicznych.

Received: 28.07.2021, Revised: 29.07.2021