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ORIGINAL PAPER

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CONVENTIONAL POOL FISH PASS PROJECT FOR SMALL THRESHOLD

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ABSTRACT

Fish migrate alongside the river in search of food, suitable hiding places and spawning grounds during the various seasons and periods of their lives. Damming a river with a weir or other artificial dam disrupts these normal life processes or even makes them impossible. The main way to overcome this problem is to build fish passes. Passes are facilities that allow fish and other aquatic organisms to migrate up and down the river through barriers such as thresholds, dams and weirs. Conventional solutions of fish pass construction have the most significant number of studies both in the literature as well as in engineering practice. Therefore, their design methodology is widely available. It considers, first of all, hydraulic and granulometric parameters, conditions of particular structure elements locations, but also properties of migrating fish species. This study covers the concept of restoration of a dam on the Radomka river with a conventional pool fish pass. The pool fish pass will be located along the river bank, allowing the migration of fish identified in the study area. Additionally, it was developed a concept of bed material mixture, consisting of clastic material in the form of sand with addition of a coarser gravel-stone fraction.

Key words: fish pass, water structures, hydrotechnics, weir, environmental impact

INTRODUCTION

Water is a crucial and multipurpose resource in the context of the regional economy. Whenever water structures are mentioned in the literature, they should be understood as the main object together with related technical equipment and installations. According to the Polish Regulation of the Ministry of Environment of 2007 on the technical conditions to be met by hydrotechnical structures and their locations, these are structures serving water management as well as development and use of water resources (Rozporządzenie Ministra Środowiska z dnia 20 kwietnia 2007 r. w sprawie warunków technicznych, jakim powinny odpowiadać budowle hydrotechniczne i ich usytuowanie).

Water management requires a creation of water storage facilities as it is one of the oldest branches of civil engineering serving urban development. The first record of dam construction date back to 4,000 BC and concern an erratic stone dam, located in Egypt, which was used to improve the irrigation of fields. Later, the information about water construction also appeared in Mesopotamia, ancient India, Greece and Rome. Significant development of water construction and damming structures occurred at the end of the 17th century. The constructed water barrages were intended to create local sources of cheap energy used for on-site generation and improvement of waterways. A breakthrough in hydraulic engineering and its rapid development occurred at the end of the 19th century. The invention of a way to transmit electricity made it

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possible to use hydroelectric power, regardless of the location of its source. At the same time, the expansion of industry reduced construction costs, what enabled to build large hydroelectric structures (Fanti, Fiedler, Kowalewski & Wójcicki, 1972).

Economic development has generated different approaches to water management. A sectoral approach with excessive emphasis on only some branches of the economy is now countered by a holistic, sustainable form of water management. Sustainable development involves the thoughtful use of resources in such a way that they be sufficient to build the wealth of a present generation, but can also meet the needs of the future. The sustainable development is currently the most important trend in urban development. The integrated urban management is based on four pillars: equal access to a high-quality natural environment, efficient use of natural resources for economic benefits, preservation of ecological balance and the ability of the city's natural system to regenerate. The urban development consists in a development of diversified economic branches and introduction of transport improvement. Economic development generates the need to supply increasingly more water – for this purpose hydro technical structures are being introduced into the urban structure.

Damming a river has many positive and negative effects. On the one hand, it increases flood protection of adjacent areas to a limited extent and allows water to be stored and used in times of drought, for irrigation, municipal management, power generation and recreation. On the other hand, it influences changes in the processes taking place in the river, the living conditions of plants and especially aquatic organisms (Wołos, 2007). Fish belong to the most migratory aquatic organisms. Fish migrations result from their diverse needs and are a basic feature of their biology. There are different causes and types of migration of aquatic organisms. These causes can be divided into internal and external factors. Internal factors may include genetic and physiological conditions of individual species, as well as the need to avoid predators. External causes include temperature, light, food availability, hydrological conditions and water quality (Zdanowska, 2010). The construction of artificial dams on water bodies is a physical barrier to migratory animals (Bartnik et al., 2015). On the other hand, Bajkowski (1998) demonstrated that such structures can create favourable conditions for increasing oxygen saturation in the water, being listed as one of the most important environmental factors.

The damming up of water may result in the reservoir creation and thus different depths and widths of the riverbed along its length. As the water depth changes, the hydrodynamic conditions change, i.e. the average flow velocity and the velocity and turbulence distribution of the stream (Dąbkowski, Skibiński & Żbikowski, 1982). The stream velocity and the physical forces associated with it form the most important environmental factor affecting organisms living in watercourses (Allan & Castillo, 1998). A significant velocity reduction in the bottom region to a scour area of flow is referred to in the literature as the bedrock layer (Urbański & Siwicki, 2004).

The negative impact of river development on ichthyofauna led to the need to counteract the phenomenon. Therefore, the construction of devices that allow fish migration has been developed (Jędryka, 2007). Migration of all fish species is a necessity and carried out over various distances. Potadromous (stationary, local) fish migrate within the boundaries of a single river (lake, reservoir) or river system – only in inland waters. For this group, an unobstructed watercourse over a distance of several to several dozen kilometres is essential for life, allowing migration between feeding and spawning grounds. Diadromous fish (bi-environmental, migratory) migrate between inland and marine waters and therefore require an unobstructed watercourse, often along its entire length (Milton, 2010).

The main principle of fish pass design is to achieve a gentle or cascading connection between the upper and the lower water level. Therefore aquatic organisms have the opportunity to migrate upstream when the local water surface inclination is eliminated over a longer section of the watercourse, contributing to a water flow velocity reduction (Jędryka, 2007).

The fish ladders may take various forms, being more or less close to the natural channel's shape. They can be divided into:

- circulatory channels (bypassing damming structures, connecting the riverbed upstream and downstream of the structure), being simultaneously

shaped as much as possible to resemble natural watercourses;
- cascades of small pools connected by ramps with a small angle of inclination or by a series of steps with a small slope;
- stone ramps, separated from the rest of the overflow by a partition through a narrow, built-in additional overflow opening of the damming structure (Zbikowski & Zelazo, 1993).

Natural fish passes should imitate, as closely as possible, streams with a higher inclination or natural river rapids. They should be built of natural materials, such as boulders, stones. Such structures potentially become a new habitat for aquatic organisms and more easily blend into the landscape. Completely artificial fish ladders are built as well. Finally, in special situations, when large differences between levels are to be overcome at the existing dam structures, it is necessary to use other solutions – elevators and sluices for fish (Mokwa, 2007, 2010; Hämmerling, 2019).

Special structures include fish elevators – devices for lifting fish from the lower to the upper baffle station. Fish are attracted to a catching cage equipped with a transport pool at the lower station. Such devices are used at damming levels exceeding 10 m, often as the only solution to the problem of fish migration, for instance in the case of high dams. Another special solution, a sluice gate, is an elongated pool with closing, controlled gates on upstream and opening downstream of the sluice. The water transfer through the bypass or the controlled sluice opening is produced by the attracting current. In case of lack of space, sluice gates are used at high water levels.

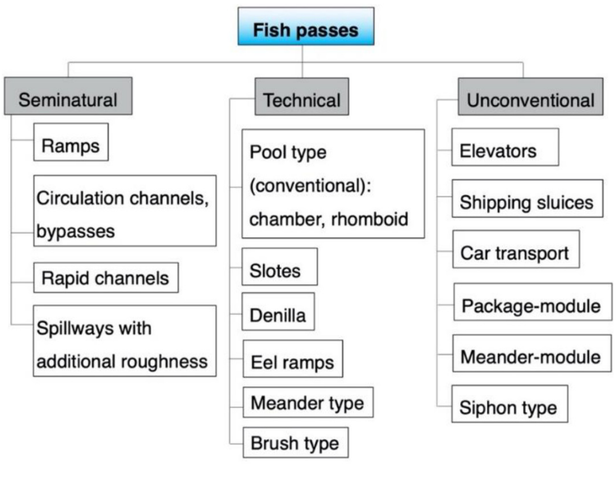

Fig. 1. Classification of fish ladders (own elaboration basing on Mokwa, 2007, 2010; Książek, Strużyński & Wyrębek, 2011; Hämmerling, 2019)

Hydromorphological conditions of a river bed, including spatial distribution of erosion and accumulation processes, influence the conditions of fish migration. Considering this four types can be found: food migration, spawning migration, compensatory migration and migration related to biotope change. Figure 1 presents the classification of fish ladders according to their type (Mokwa, 2007, 2010; Hämmerling, 2019).

Fish passes belong to the oldest structures allowing fish to migrate upstream. The size of individual elements and, thus, of the whole structure depends mainly on:
- the sizes of fish species migrating up a given watercourse,
- the level difference between the inlet and outlet of the fish ladder (Hämmerling, 2019).

Streamlining of the stage allowing the aquatic organisms' migration should be preceded by a concept considering a thorough analysis of formal, legal, environmental and technical conditions, water distribution at the junction and various possible alternatives. Environmental conditions include ichthyological, hydrological and morphological characteristics (Mokwa & Tymiński, 2017; Kasperek, Szkudlarek & Mokwa, 2019; Petkova, Kanev, Dimitrova, Kisliakov & Uzunova, 2019).

The most common causes of fish pass failures include weak attracting current, improper inlet location, too large differences between levels of pools, too small pools or too large openings between them, periodical lack of water in the fish ladder, uncovering the entrance to the fish ladder, obstruction of the fish ladder caused by siltation or litter in the fish ladder, poaching. A serious threat to fish are power plant turbines, with inlets equipped with grids (Knaepkens, Maerten & Eens, 2007; Cooke & Hinch, 2013; Radecki-Pawlik et al., 2019). The fish passes contribute to mitigating the negative environmental impacts of barriers such as weirs, dams and barrages, but their construction does not eliminate these losses (Chanson & Leng, 2021).

POOL-TYPE (CONVENTIONAL) FISH PASS

The general principle of operation of conventional fish passes is a cascade of pools connecting the lower damming structure stand with the upper one. Dimensions of pools and openings depend on fish species migrating in a given watercourse, water surface gradient between the inlet and outlet of the fishway and size and character of the watercourse. Fish move from one pool to another through openings in partitions located at the bottom or the top of the wall through an overflow. Migrating fish have to overcome strong water currents only when crossing a single passage or overflow, whereas pools with weaker water currents shelter them as a resting place. The high roughness materials are used to enable the zoobenthos to overcome the strong water currents (Baumgartner et al., 2021).

The pool fish pass design usually assumes that the structure is routed along a straight line – from the upstream to the downstream. It is also possible to design the fishway along curves or bends created by individual sections' direction changes. The channel route in the inlet area and within the fishway itself can be developed using circular curves. However, such curves occur rarely in nature. The transition from circular curve to straight current or the transition from one curve to another alternates rapidly, what is unfavourable for hydrodynamic reasons (Fig. 2).

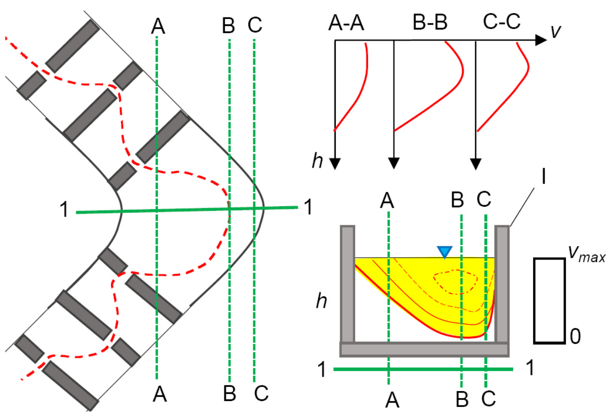

Fig. 2. Hydrodynamic conditions in pool fish pass, where: h – water depth; v – stream velocity; v_{max} – maximal stream velocity; 1-1, A-A, B-B, C-C – cross--sections; I – the wall exposed to deformation and erosion (own elaboration)

In the location of a sudden water level increment under centrifugal force influence, a sudden rise in the water level can occur at the pool concave shore. This causes an unfavourable inward currents arrangement and may lead to bottom deformation. This phenomenon does not occur when the route is developed based on higher degree curves. If possible, it must be located a water discharge downstream the weir or turbine outlet to avoid a "dead angle" or "dead zone". The maximum flow velocity depends on the differences between water levels in the pools. Therefore it is a factor limiting the fish ability to move through the individual fishway elements. The optimum water level difference between pools is 15–20 cm. Conventional pooled fish passes also work at low water levels, what is their leading advantage. When the water does not overflow the upper edges of the pools, the orientation of fish in the fishway is assisted by the alignment of current lines. This type of fish pass is designed as a concomitant device for small weirs on lowland rivers to allow aquatic organisms to migrate.

Among the technical considerations, there are the characteristics of the water stage, the task set for it, the existing infrastructure (small hydropower plant), the water management conditions and the hydraulic conditions of water flow, etc. The most important factors in the design of fish passes, however, include consideration of optimal location, water outlet from the downstream side, attracting current conditions, water inlet from the upstream side, hydraulic conditions in the fishway and geometric fishway parameters (Mokwa, 2007, 2010; Hämmerling 2019; Figs 3 and 4). The fishway inlet is important for the fish pass effectiveness. It should ensure undisturbed water inflow and safe exit of migrating organisms. The attracting current obtained by the outflow from the fish pass is a decisive element for the possibility of finding the entrance to the fish pass. Hence, the current should be perceptible to fish, what means that it should have higher velocity than in the riverbed, but within the range of swimming capabilities of migrating species.

The water outlet from the fish pass should be located just below the turbulence zone at the dam structure outlet. It should be located parallelly to the current or directed at the angle of 30°. The inlet should not be located perpendicularly to the water outlet from the

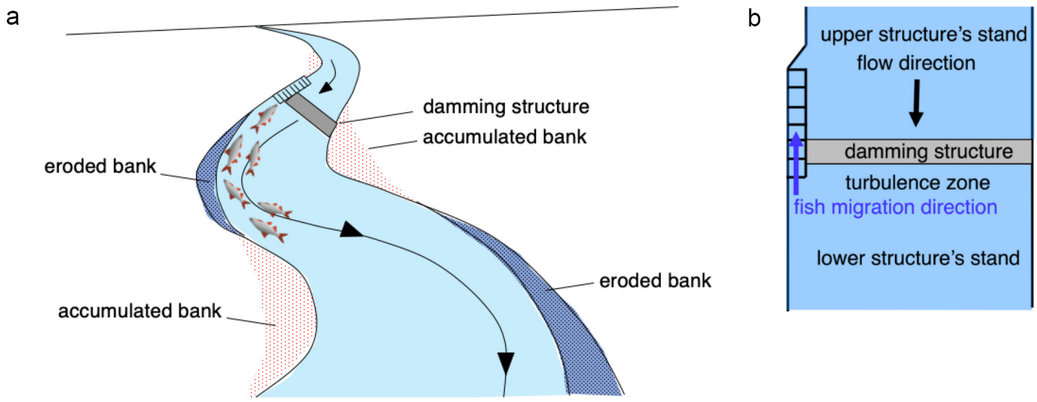

Fig. 3. Optimal fish pass inlet location: (a) inlet location in a streamline; (b) plan view (own elaboration basing on Hämmerling, 2019; Plesiński, Radecki-Pawlik & Suder, 2020)

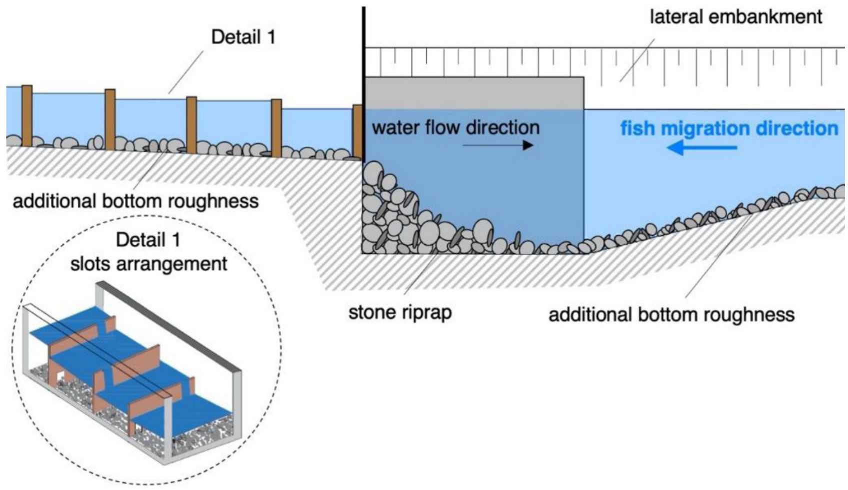

Fig. 4. Schematic view of a conventional fish pass including bed development (own elaboration)

downstream side, what determines the possibility of finding the pass and entering it by migrating ichthyofauna. Moreover, the outlet should ensure entry to the fishway at variable water levels including its annual variations. It should also be lighted, preferably with daylight. The optimal location of the inlet should be as close to the dam or turbine outlet as possible. In case of a small hydropower plant with a diversion channel, it may be necessary to build two fish passes operating simultaneously to ensure migration both through the channel and the river (Mokwa, 2007, 2010; Hämmerling, 2019).

MATERIAL AND METHODS

This publication assumes the design of a conventional fish passage accompanying a wooden piling structure – the remains of an old mill named Olszanka on the Radomka river (Fig. 5) in the Masovian Voivodeship. The river in this area meanders eastward. Its right bank is mostly covered with pine trees with forest ducts. The left bank is a wasteland and meadows bordered by a railroad track.

Within the researched area, mainly roaches, ides and pikes can be met, which, in adult life, reach the

Fig. 5. Remains of the old impoundment on the Radomka river (photo by M. Kiraga)

maximum body length of 0.3, 1.5 and 0.8 m, respectively. Therefore, the following parameters of the pool fish pass were assumed: pool length $I_b = 1.5$ m; pool width $b = 1.5$ m; minimum water depth $h = 0.6$ m; width of the passage in the partition wall of $b_s = 0.25$ m; height of the passage $h_s = 0.25$ m; maximum water level difference $\Delta h = 0.2$ m, thickness of the partition walls $I = 0.1$ m. Overflows are not included. Stream velocities shall not exceed a maximum value of $v_{max} = 2.0$ m·s^{-1} and volumetric energy dissipation shall not exceed $E = 150$ W·m^{-3} to ensure low turbulence in the pools (Larinier, 2002). In order to avoid unfavourable hydrodynamic conditions, which could result in increased concrete deformation, the pass is proposed in the form of a straight section, with alternating inlets to the chambers.

Firstly, the number of pools was calculated considering the total difference between water levels that the fish have to overcome as well as the difference between the maximum water level and the bottom water level according to Formula (1) (Fundacji WWF Polska, Food and Agriculture Organization of the United Nations [FAO], Ministerstwo Gospodarki Morskiej i Żeglugi Śródlądowej [MGMiŻŚ], 2016):

$$n = \frac{h_c}{\Delta h} - 1, \tag{1}$$

where:
n – number of fishway pools [-],
h_c – total difference between water levels [m],
Δh – difference between water levels ($\Delta h_{max} = 0.18$ m).

Then, the slope of the fishway bottom was calculated as:

$$i = \frac{\Delta h}{I_b}, \tag{2}$$

where:
i – inclination of the fishway bottom [-],
I_b – pool length [m].

Subsequently, the maximum stream velocities occurring in the slots were calculated as:

$$v_{s\max} = \sqrt{v_0^2 + 2g \cdot \Delta h}, \tag{3}$$

where:
v_{smax} – maximum flow velocity in the slot [m·s^{-1}],
v_0 – stream velocity [m·s^{-1}],
g – gravitational acceleration (g = 9.81 m·s^{-2}).

Then the pool discharge coefficient was estimated according to Formula (4):

$$Q_s = \psi \cdot A_s \cdot \sqrt{v_0^2 + 2\mathrm{g} \cdot \Delta h}, \quad (4)$$

where:
Q_s – slot discharge [m^3·s^{-1}],
ψ – flow coefficient ($\psi = 0.65085$) [-] (Fundacji WWF Polska, FAO & MGMiŻŚ, 2016),
A_s – slot area [m^2].

Kinetic energy in each pool could be calculated basing on Formula (5):

$$E = \frac{\rho \cdot \mathrm{g} \cdot \Delta h \cdot Q_s}{b \cdot h_m \cdot (I_b - i)}, \quad (5)$$

where:
E – energy in pool (E = 150 W·m^{-3}),
ρ – water density (ρ = 1,000 kg·m^{-3}),
b – pool width (b = 1.5 m),
h_m – minimal average water depth [m].

Due to the permissible value of the parameter E = 150 W·m^{-3}, the minimum average water depth was calculated according to Formula (6):

$$h_m = h + \frac{\Delta h}{2}. \quad (6)$$

After transformation of Formula (5), Formula (7) was obtained:

$$I_b = \frac{\rho \cdot \mathrm{g} \cdot \Delta h \cdot Q}{E \cdot h_m \cdot b} + i. \quad (7)$$

Finally, the total length of the fish pass (L_c) was calculated based on Formula (8), considering pool number (n) and the length (I_b) of each pool:

$$L_c = n \cdot I_b. \quad (8)$$

POOL-TYPE (CONVENTIONAL) FISH PASS CONCEPT

Calculated geometrical parameters of the designed fish pass are summarized in Table 1. The overflows between the pools work as non-submerged. Calculations were based on available hydrological and ichthyological data. The number of pools according to Formula (1) is:

$$n = \frac{3.3}{0.18} - 1 \approx 17.$$

The bottom inclination based on Formula (2) was calculated as:

$$i = \frac{0.18}{1.5} = 0.12\,[-].$$

River flow velocity v_0 = 0.30 m·s^{-1} was assumed based on the web portal szlaki-kajakowe.pl (online 09.09.2022). Maximum flow velocities occurring in slots based on Formula (3):

$$v_{s\max} = \sqrt{0.3 + 2 \cdot 9.81 \cdot 0.18} = 1.96\ \mathrm{m{\cdot}s^{-1}}.$$

The maximum flow velocities are lower than the allowable maximum v_{max} = 2.0 m·s^{-1}.

The coefficient of expenditure in slots and overflows based on Formula (4) is:

$$Q_{s\max} = 0.65 \cdot 0.0625 \cdot \sqrt{0.3 + 2 \cdot 9.81 \cdot 0.18} = $$
$$= 0.080\ \mathrm{m^3{\cdot}s^{-1}}.$$

The minimum average water depth after applying Formula (6) is equal to:

$$h_m = 0.6 + \frac{0.18}{2} = 0.7\ \mathrm{m}.$$

The length of the pool is based on Formula (7):

$$I_b = \frac{1{,}000 \cdot 9.81 \cdot 0.18 \cdot 0.080}{150 \cdot 0.7 \cdot 1.5} + 0.1 = 1.10\ \mathrm{m}.$$

This dimension allows to maintain low turbulence within the stream.

With a water depth of 1.0 m, a gravel layer covering the pool bottom of 0.2 m and a water level difference of $\Delta h = 0.18$ m, the height of the lowest partition wall related to the river flow will take the following value:

$$h_{w1} = 1.0 + 0.2 + 0.18 = 1.38 \approx 1.40 \text{ m.}$$

In contrast, at the highest partition wall:

$$h_{w2} = 0.8 + 0.18 = 0.98 \approx 1.0 \text{ m.}$$

Calculated from Formula (8), the total length of the fish pass pools is equal to:

$$L_c = 17 \cdot 1.1 = 18.7 \text{ m.}$$

The fish pass is a concrete structure, therefore it is vulnerable to alkali–silica reactions, such as cracking, movements and displacements. Compliance with specific hydraulic conditions within the structure may be a way to minimize deformation. The velocity in the slots was compared with the allowable velocities via assigned for the various building materials (Table 2). Exceeding these values may result in material deformation or excessive erosion by flowing water (Dąbkowski et al., 1982).

The designed construction should be located at the weir, on the right bank of the river, by the location-based restrictions. It consists of 16 chambers, each 1.10 m long and 1.5 m wide, with a total length of 17.64 m. The dimensions of the chambers consider the maximum body length of the largest fish species found in the Radomka river. It is equipped with two emergency closure guides. The pools of the fish ladder are separated by vertical wooden partitions, each 0.1 m thick, mounted perpendicularly to the pass axis

Table 1. Summary table of the fish pass working parameters (own elaboration)

Element	Symbol	Unit	Value
Number of pools	n	–	17
Bottom inclination	i	–	0.12
Maximum flow velocity in slot	$v_{s\max}$	$\text{m}\cdot\text{s}^{-1}$	1.96
Coefficient of expenditure in slots and overflows	$Q_{s\max}$	$\text{m}^3\cdot\text{s}^{-1}$	0.080
Minimum average water depth	h_m	m	0.080
Length of the pool	I_b	m	1.10
Height of the lowest partition wall	h_{w1}	m	1.40
Height of the highest partition wall	h_{w2}	m	1.00
Total length of the fish pass	L_c	m	18.7
Opening width	b	m	1.50
Inclination of the fishway bottom	$1 : m$	–	1 : 2

Table 2. Allowable velocities for different construction materials (own elaboration basing on Jędryka, 2007)

v_a [$\text{m}\cdot\text{s}^{-1}$]	Material type
5.0	for concrete slabs at least 1.0 m thick, coarse stone-filled caskets and stone-mesh mattresses, 1.0 m thick
4.0	for concrete slabs with a thickness of 0.4–1.0 m and for double, carefully made stone pavements with a replacement diameter of at least 0.25 m
3.5	for stone riprap with a substitute diameter of at least 0.30 m (if riprap reinforcement with piles or rails is used, this speed is increased to 4.0 m)
2.0–2.5	for 1.0 m thick fascine mattresses

(Figs 6a and 6b). The fish pass entrance is located at the bank, where the water current is the strongest, what provides the possibility of fish migration upstream in the main current. To induce it, the stream velocity should range between 0.8 and 2.0 $m \cdot s^{-1}$. The calculated maximum velocity meets this condition. The exit from the fishway is a vertical slot. The bottom of the facility should be covered with a 20 cm thick layer of gravel, however, if this granulation is not available in the vicinity of the construction site, it must be delivered according to the schedule. A proposition of the bed material granulation curve considers demands of specific fish species (Fig. 6c). Regular maintenance of the fish pass should be carried out to ensure the best possible efficiency and to eliminate possible obstacles such as blockages, rubbish or debris at the entrance and passages.

SUMMARY AND CONCLUSIONS

The designed conventional pool fish pass will accompany the reconstructed damming structure on the Radomka river. The structure, located on the right bank of the river, consists of 17 chambers, each 1.10 m long and 1.5 m wide, with a total chamber length of 18.7 m. Pools are separated by 0.1 m thick vertical walls fixed perpendicularly to the fishway axis. The height of the lowest partition wall is 1.40 m, while the highest one – 1.00 m. The maximum difference between water levels is planned to be equal to 0.18 m. The water velocity in the slots is below allowable, ensuring the proper operation of the fish pass and preventing excessive deformation processes and concrete degradation.

Local stream velocity values and hydraulic gradient between pools are important from the point of view

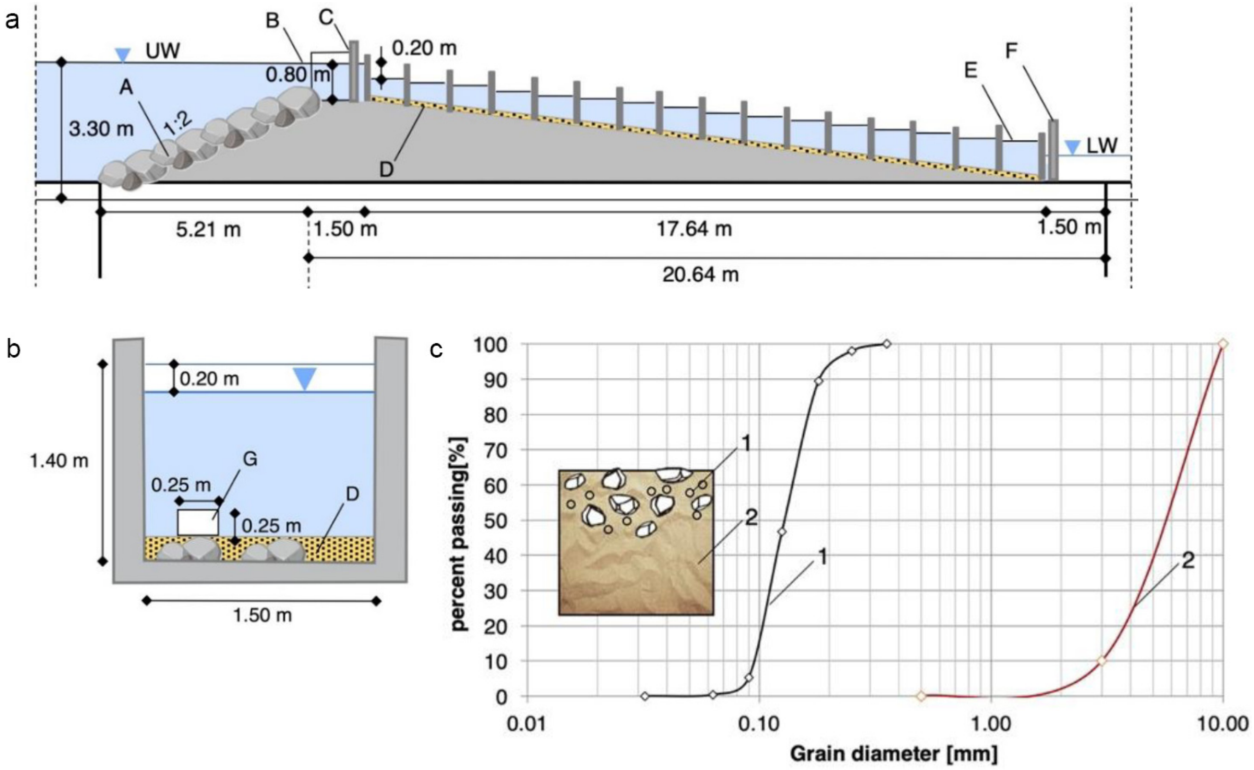

Fig. 6. Pool-type straight (conventional) fish pass conception: (a) side view; (b) cross-section; (c) granulation curve of bed material, where: UW – upstream water surface level; LW – downstream water surface level; A – rapid pool; B – unsubmerged apron; C – upstream emergency locking slides; D – bed material; E – maximal water depth in the pool; F – downstream emergency locking slides; G – submerged slot; 1 – granulation curve of the clastic material; 2 – granulation curve of rough supplementary material (own elaboration)

of fish pass operation. It should be ensured that a minimum depth of water flow is maintained under various hydrological conditions. Due to the ichthyofauna variability, it should be ensured that at each point of the fish pass, the maximum water flow velocity possible to be overcome by the weakest organisms is not exceeded. The plan view of the pass is straight, and the slots lie alternately. The exact position of slots, angles and water circulation should be the result of hydraulic modelling studies performed in, for example, two--dimensional programs for mathematical modelling of flow in open channels.

Authors' contributions

Conceptualisation: M.K. and P.K.; methodology: P.K.; validation: M.K. and M.N.; formal analysis: M.K. and P.K.; writing – original draft preparation: P.K. and M.K.; writing – review and editing: M.K. and M.N.; visualisation: M.K. and P.K.; supervision: M.K.

All authors have read and agreed to the published version of the manuscript.

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KONCEPCJA KOMOROWEJ PRZEPŁAWKI DLA RYB, TOWARZYSZĄCEJ MAŁEJ BUDOWLI PIĘTRZĄCEJ

STRESZCZENIE

Ryby migrują wzdłuż rzeki w poszukiwaniu pożywienia, odpowiednich kryjówek i tarlisk w różnych porach roku i okresach swojego życia. Spiętrzenie rzeki jazem lub inną sztuczną zaporą zakłóca procesy życiowe ryb, a nawet całkowicie je uniemożliwia. Głównym sposobem na rozwiązanie tego problemu jest budowa przepławek dla ryb. Przepławki to obiekty umożliwiające rybom i innym organizmom wodnym migrację w górę i dół rzeki przez przeszkody takie jak progi, tamy i jazy. Konwencjonalne rozwiązania konstrukcji przepławek dla ryb mają największą liczbę opracowań zarówno w literaturze, jak i praktyce inżynierskiej. Metodyka ich projektowania jest więc powszechnie dostępna. Uwzględnia ona przede wszystkim parametry hydrauliczne i granulometryczne, warunki lokalizacji poszczególnych elementów budowli, ale także właściwości migrujących gatunków ryb. Niniejsze opracowanie obejmuje koncepcję odbudowy zapory na rzece Radomce za pomocą konwencjonalnej przepławki komorowej. Przepławka będzie zlokalizowana wzdłuż brzegu rzeki, umożliwiając migrację ryb zidentyfikowanych w rejonie badań. Dodatkowo opracowano koncepcję mieszanki materiału dennego, składającego się z materiału klastycznego w postaci piasku z dodatkiem grubszej frakcji żwirowo-kamiennej.

Słowa kluczowe: przepławka dla ryb, budowle wodne, hydrotechnika, próg piętrzący, wpływ na środowisko