Fish ladder design in terms of a large difference in water level

M. Mazurkiewicz
Support expert in hydro engineering
Hydroinvest Ltd
Warsaw, Poland

W. Wiśniewolski
Support expert in river fisheries
The Stanislaw Sakowicz Inland Fisheries Institute
Warsaw, Poland

I. Suslo
Design engineer
Hydroinvest Ltd
Warsaw, Poland

M. Pilecki
Design engineer
Hydroinvest Ltd
Warsaw, Poland

Intro

One of the projects of Hydroinvest was to develop a concept of a fish ladder in the area of the newly designed multi-purpose 'Kąty-Myscowa' reservoir. The facility includes a 44-meter-high dam dividing a river which constitutes a major obstacle for migrating of aquatic fauna. The technical solution for the fish ladder is challenged by huge water level fluctuations in the reservoir, the type of dam, and a variety of fish species and sizes. The reservoir will make a local impact on the natural habitats' character. Moreover, the river's permeability will interrupt migration of aquatic organisms. The designed fishways will minimize negative effects of the new reservoir.

1. Background

1.1 Specification of the future reservoir

The planned Kąty-Myscowa dam reservoir is located in the Low Beskids (Jasło Country, Podkarpackie Voivodeship, Poland). It is impounded by an earthfill dam located at 141+400 km of the Wisłoka River at the biggest narrowing of the river's valley at the Kąty village. The catchment area of the river up to the cross-section of the dam of the future reservoir is 297 sq km, collecting mainly water from the Magura Range and the Beskid Dukielski Mountains. The springs of the Wisłoka River are located near the former village of Radocyn, right on the border with Slovakia.

Mountainous, the river meanders along the riverbed full of boulders. The most important tributaries of the Wisłoka river to the planned dam are: the right-bank Wilsznia, Krempna, Ryjak and the left-bank Rzeszówka, Świerzówka and Zawoja. A characteristic feature of the rivers in this part of the Wisłoka are large slopes of the channel (over 50 ‰). In the section of the Wisłoka River, which is to be flooded with the waters of the future reservoir, the drops are between 6.7-5.7 ‰.

The planned reservoir will be characterized by a high variability of water levels, which are: maximum reservoir level MaxPP at 356.0 m AMSL, normal damming level NPP at 350.7 m AMSL, minimum damming level MinPP at 333.0 m AMSL. These differences result from the assumed task of providing alimony to the towns below in the periods of low flows and from the flood protection function.

1.2 Dam structure

The designed dam, with a body height of 44.26 m, will be used for permanent damming of water in order to provide water to cities and settlements along the Wisłoka Valley and to protect them against flooding. The damming structure will be erected in changing soil conditions. It is planned to make the embankment of the front dam by sealing the body with a central aluminum core. The height of water damming H in the area of the water outlet from the rapids basin is about 40.4 m.

1.3 Variant analysis

As part of the analysis, many types of fishways were considered, such as:
- catching fish and transportation;
- natural ramp;
- fish elevator;
- circulating fish passes;
- slot passes.

The technical-type vertical slot pass, connecting the upstream and the downstream of the dam, located along the designed overflow spillways, was chosen as the most favourable fish migration system.

2. Characteristics of technical slot fish passes

The slot pass consists of a concrete canal with transverse partition walls. There is a variation of the classic pool pass whereby the cross-walls are notched by vertical slots extending over the entire height of the crosswall, which has one or two slots depending on the size of the watercourse and the discharge available. These slots are located at the side wall of the fish pass canal. This type of fishways is used for small and medium water level differences, for dams with variable upstream water level. It is most likely the best type of technical fish pass, suitable for all species of fish and invertebrates, thanks to the continuity of the natural bottom substrate.

3. Description of the slot fish pass concept

The performed hydraulic calculations show that the fish pass will be about 1,350 m long, including the intake section at 125 m. The intake section enables gravity water intake to the fish pass. The water intake will be made through the inlets in every second pool. There are favourable conditions for water intake and fish pass operation in this solution.

The planned fish pass runs through mountainous areas and overcomes the obstacle of a 40-m-high earth-filled dam. Therefore, it is a very complex hydraulic facility. Sections with different characteristics and accompanying engineering facilities can be distinguished in this structure (Fig.1).

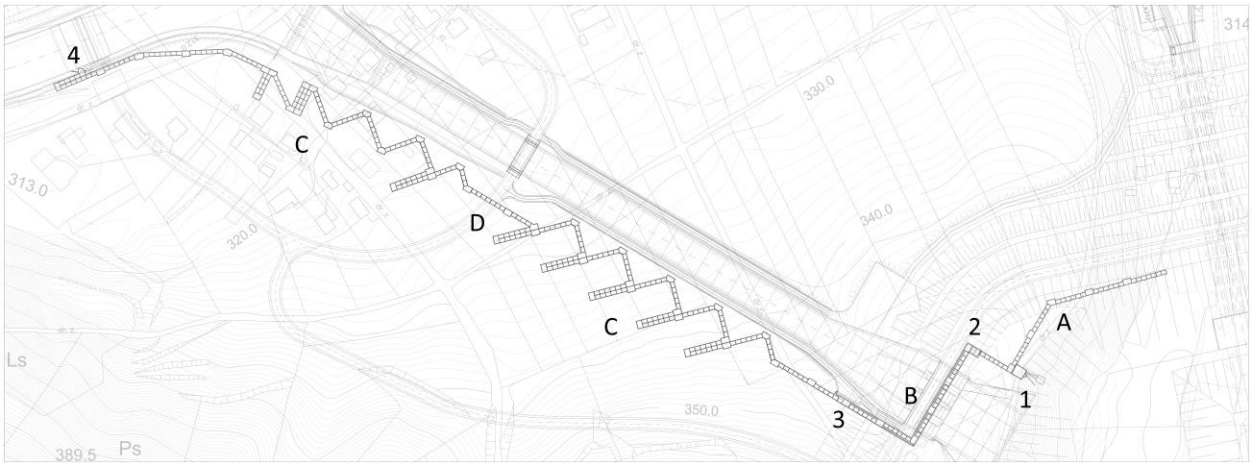


Fig. 1. The fish pass plan

Along the run of the fish pass, from the water intake from the reservoir to its discharge into the river below the dam, it will be composed of four types of structures:
a) the water inlet (fish entrance) section (Fig.2);
b) fish pass in the gallery crossing the dam;
c) open section running through the territory below the dam (Fig.3);
d) fish pass in the gallery crossing the road embankment of the bridge over the spillway.

And four engineering structures:
1 - water timing structure with a supply pump station (Fig.6);
2 - floodgate (entrance to the dam gallery);
3 - exit from the dam gallery;
4 - water outlet (fish pass exit) at the weir with the discharge to the river at the tailwater.

3.1 Basic section geometry

Six passage pools and one resting pool form a basic section, repeatable over the entire length of the fish pass. The typical width of the passage pool will be 2.20 m, resting pool: 3.20 m. The water level difference between pools will be at h = 0.11 m.

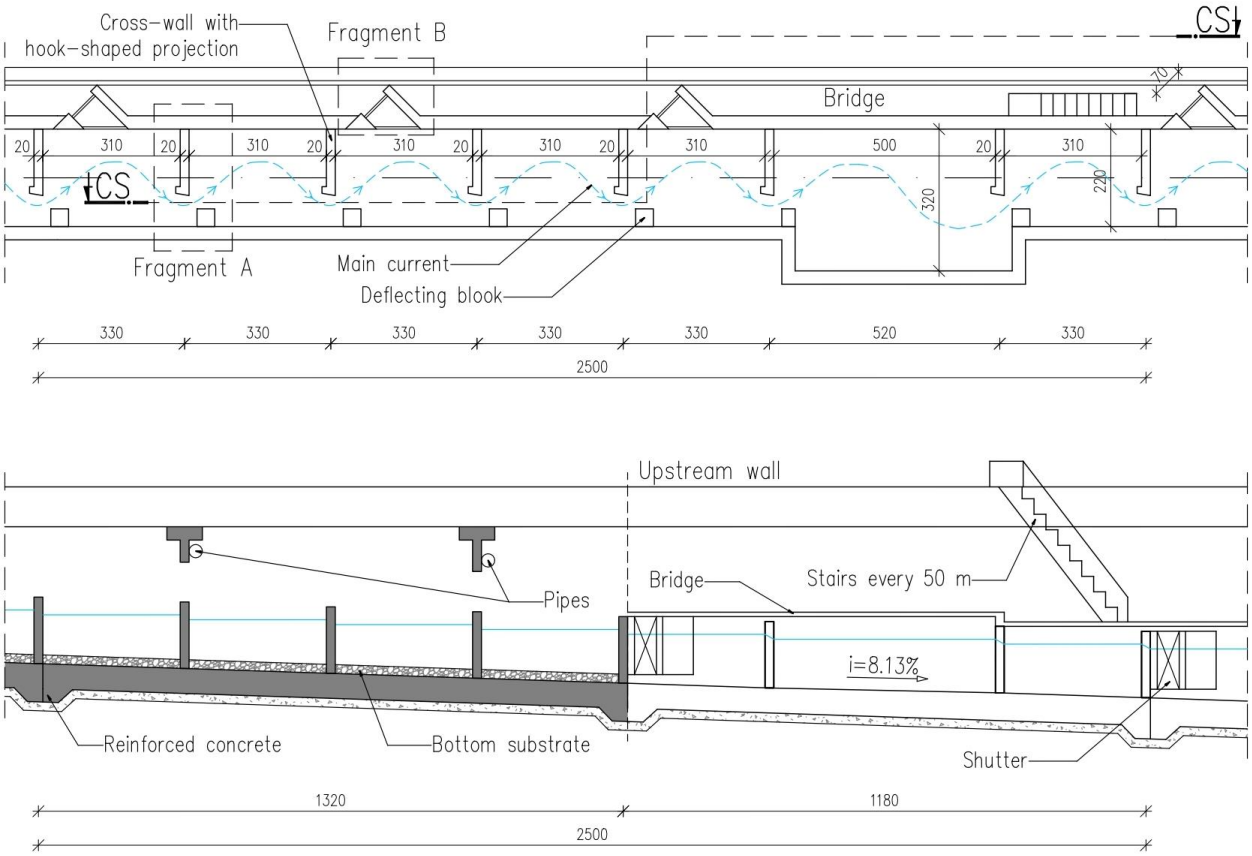


Fig. 2. The inlet section plan and cross-section

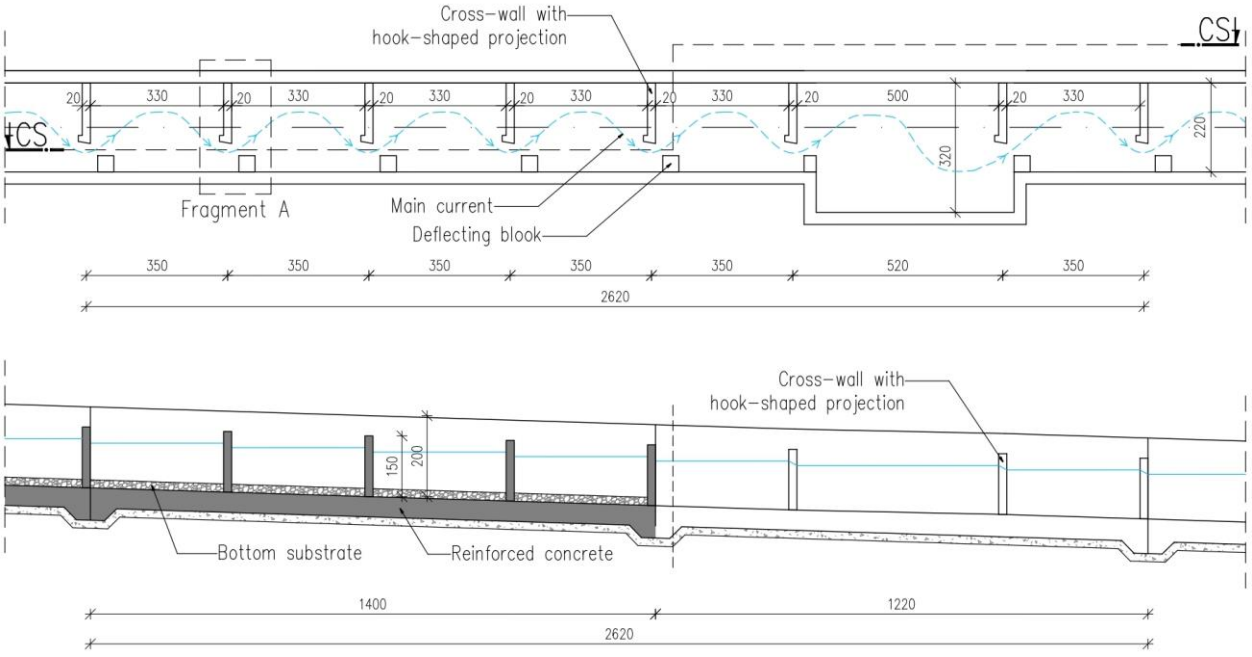
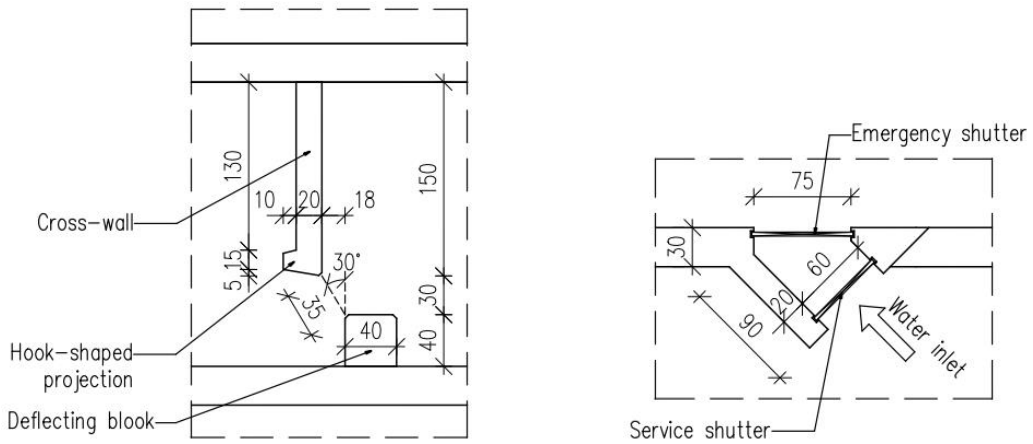


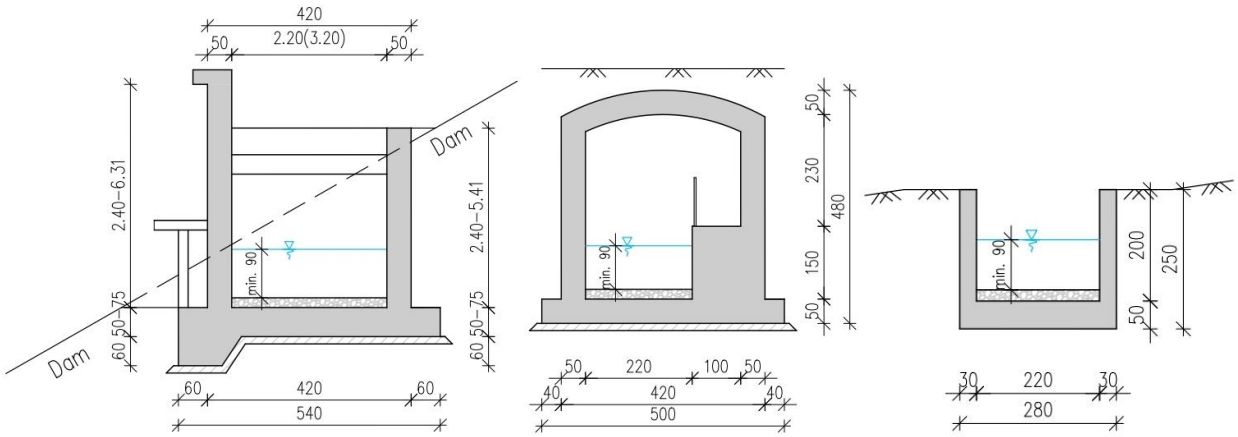
Fig. 3. The open section plan and cross-section



Fragment A *Fragment B*

Fig. 4. Fragments A and B

The fish pass basic section will be divided by expansion joints into two parts: 4 passage pools, each with the net length of 3.10-3.30 m, and a resting pool with a net length of 5.00 placed between two passage pools with the net length of 3.10-3.30 m. The basic section will be the above-mentioned two parts with a total gross length of 25.0-26.2 m. The water level difference between two typical sections will stand at 0.77 m.



1 *2* *3*

Fig. 5. The fish pass cross-sections. 1 - fish entrance section; 2 - fish pass in the gallery crossing the dam; 3 - open section.

3.2 Operation principle of the future fish pass

The natural operation of the fish pass in both directions can take place within the water levels ranging in the reservoir between 350.70 - 346.85, i.e., during the fluctuations period $\Delta h = 3.85$ m. The operation range of the fish pass below its natural operation towards head-tail water will be increased with water pumping. For this purpose, an additional water timing structure was designed with a parallel but staggered operation of two accumulating pools.

The work of the water timing structure consists in the pump supply of both accumulating pools through the expansion pool and intermediate pool. Fish flowing from below can only reach the pool of the working stand. From

time to time the inlet gate is closed and the accumulating pool is emptied through the outlet (after its opening). The water with gathered fish flows down through a stainless-steel gutter to a tank with a lowered water level. It was assumed that the gutter would reach the level of 340.00, i.e. 1 m lower than the assumed level of the fish pass operation range. The gutter will be attached to the concrete bench placed on the slope. Any additional increase of the operation range would only require the extension of the gutter.

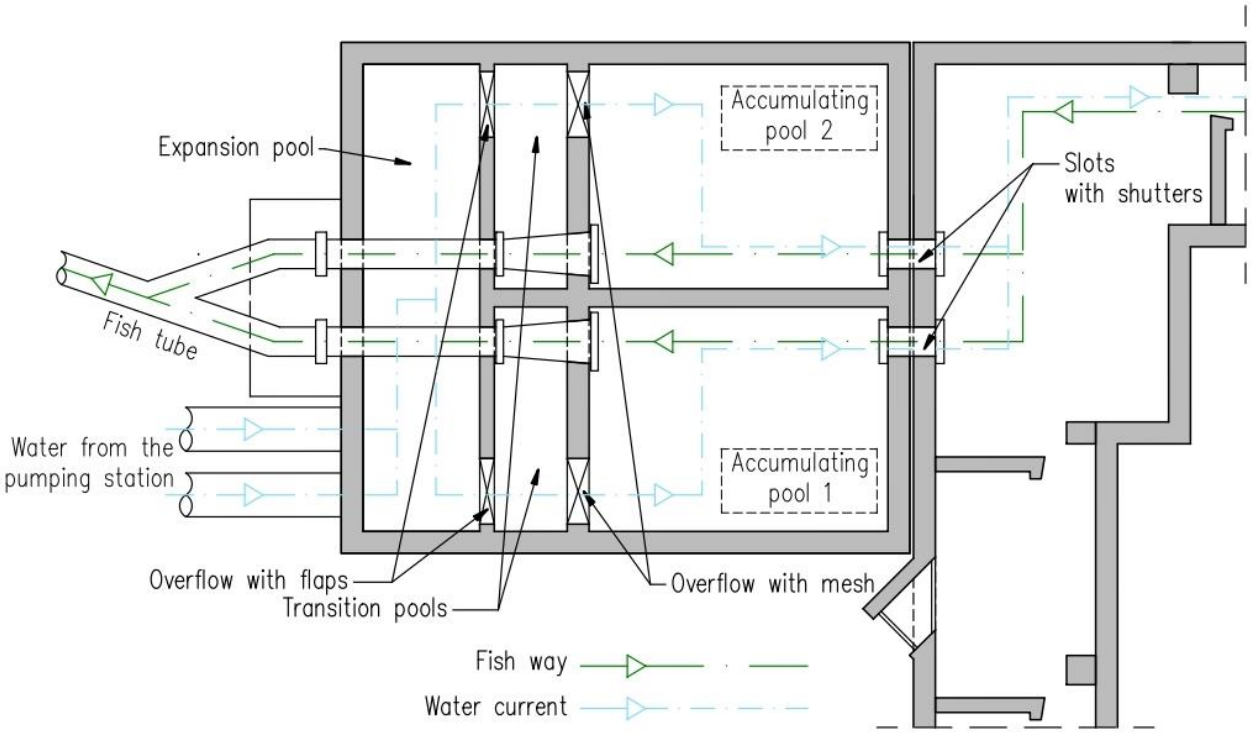


Fig. 6. Water timing structure

Six passage pools connect the water timing structure with the floodgate. The fish pass floodgate (bulkhead gates) will be located perpendicular to the dam axis at the dam crest.

The fishways will pass through the dam in a gallery. In the gallery, in addition to the pools, a 1.0-m-wide footbridge will be included in the structure. Above the extension of the resting pools, the footbridge will be led on reinforced concrete support, or a platform made of steel grate. The type of electric lighting and ventilation will be installed in the gallery as agreed with ichthyologists.

The open section led by serpentines on the left side of the spillway will end at the stabilizing step. The step will serve as a barrier to the natural migration of the river fauna. It creates conditions enabling the migrating fauna to find their way into the artificial pool of the fish pass in order to overcome the main obstacle, i.e., the dam of almost 40 meters.

On the left abutment of the step, there are three structures for draining water during normal operation. These are: a flushing channel, hydroelectric power station, and a fish pass. All these structures are involved in carrying out an equalized flow of about 2.4 m3 / s. The flushing canal will operate sporadically and remove sediments in front of the hydroelectric power station and as a backup discharge during the shutdown period of the facility.

The outlets from these three structures are led to the outlet basin of the step in the sequence from the weir: the flushing canal, hydroelectric power station, the fish pass. The outlets from the canal and the power station should lead to the abutment of the tread, similar to the outlet from the fish pass. It is inclined from the shoreline by 30°, and in front of it there is a slipway that allows a gentle discharge of water from the fish pass to the bottom of the river. If such a solution is used, the water streams from the fish pass and the power station will move in parallel. The fish pass outlet is additionally supplied with the water taken from the pipeline in front of the turbine. This inflow will increase the attractiveness of the fish pass outflow and will effectively attract fish. The attracting water flows to the

outlet pool through a surface overflow equipped with a flap and a mesh. At the outlet of the pool, there will be three discharge openings with barrage closures enabling the regulation of the speed of water flowing out of the fish pass.

During the fish pass operation in the pumping mode, when the water level in the reservoir does not allow the fish to use the inlet windows to the fish pass, the downward migration will be additionally secured with a device for catching fish on a floating pontoon. The caught fish will be transported and released to the fish pass.

4. Conclusions

- The proposed fish pass solves extremely difficult technical conditions: the difference between the upstream and the downstream water level of the dam is 40.40 meters, which must be overcome by the fauna: the water level difference in the reservoir is 17.7 m. The problem was solved by providing the two-stage operation of the fish pass, i.e. the gravity feed water supply and the forced water feed through pumping.

- The proposed design parameters of the fish pass and its planned expenditure provide appropriate migration conditions for species making up the Wisłoka fish diversity. This is indicated by the calculated maximum flow velocities occuring in the slots V = 1.47 m/s (perm. V = 1.5 m/s) and the values of the volumetric power dissipation E = 66.94 W/m^3 (perm. E = 100 W/m^3).

- Using a slot fish pass as a basic solution to ensure fish migration results from the many advantages of this type of structure in relation to other types of technical fish pass. It allows us to guarantee the possibility of migration upstream, both for species with less swimming skills and for small fish. Due to the vertical slots, the bottom of the structure is less susceptible to silting than the traditionally designed pool pass. The designed fish pass can function in a wide range of flows, variable up and low water levels.

References (10pt bold heading)

1. **FAO/DVWK**, "Fish passes – Design, dimensions and monitoring", Rome, FAO. 2002. 119p.
2. **Hydroinvest Ltd**, „Opracowanie aktualizacji koncepcji rozwiązań technicznych budowy zbiornika Kąty - Myscowa na rz. Wisłoce". Warsaw. 2021.
3. **Suslo I.,** „Projekt konstrukcji przepławki dla ryb ze zbiornika Kąty-Myscowa". Warsaw University of Technology. Warsaw. 2021.

The Authors

M. Mazurkiewicz is a senior support expert in the Hydroinvest Ltd, Poland, who obtained his master's degree in Hydro engineering at the Warsaw University of Technology, Poland. He has been working in the hydraulic industry since 1960. He headed his own firm „Project office Marek Mazurkiewicz" from 1989 to 2019.

W. Wiśniewolski PhD, DSc - a retired employee of The Stanislaw Sakowicz Inland Fisheries Institute. The expert in ichthyology and inland fisheries: fishery management, fish migration, river continuity, up- and downstream fish migration at barrages with and without hydroelectric power generation.

I. Suslo is a Hydrotechnical engineer in the Hydroinvest Ltd, Poland. He obtained his master's degree in Hydro Engineering at the Warsaw University of Technology, Poland, in 2021. He has been working in the construction industry since 2016 and has joined Hydroinvest Ltd in 2020.

M. Pilecki is a qualified Civil and Hydrotechnical engineer. He has 15 years of experience in structure designing and hydrotechnical objects, such as dams, water storage reservoirs, hydroelectric power plants and flood control systems. During this period, he has been working as a civil engineering, structure and hydrotechnical designer and project manager.