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Flow Measurement for the Design Optimization of Fish Pass Entries in a Run of River Hydropower Plant

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The International Commission for the Protection of the Rhine (ICPR) has set the objective of guarantying the upstream migration of the salmons up to Basel, Switzerland, at horizon 2020. One of the last dams to be equipped is the one of Rhinau, in France. The large turbined discharges and the specificities of the hydroelectric facility require a detailed study of the flow in the tailrace channel to guaranty a proper visibility of the fishway entries for the fish. The study is not intended to the design of the fish pass itself, but to assure that fish can find its entries located in the tailrace channel within a highly fluctuation and structured flow field. Therefore, a physical model has been built at LCH-EPFL, on which the flow in the tailrace is assessed under different turbining configurations with the help of UVP transducers. Two transducers are used to create 2D representations of the measured flow field. The transducers are mounted on a robot capable of moving in all X, Y and Z directions within an area of 2x2 meters and able to manage the triggering of the UVP at each new robot location. Three types of datasets are recorded with this system: surface flow (longitudinal and lateral velocities), sections across each fishway entry (longitudinal and vertical velocities) and temporal variations of the longitudinal jet velocities. A last numerical step filters and interpolates the raw data to render clearly interpretable plots.

Keywords: Flow field monitoring, physical modeling, fishway optimization, run of river hydropower plant

1. Introduction

The design of fishway entries has traditionally been done through the use of physical models. This is due to the complexity of the interaction between the flow in the tailrace and the flow coming from the fishway entry. This work aims at modeling the flow in the tailrace and afterbay of the Rhinau powerplant (France) in order to optimize the design of the fishway entries. A physical model and a 3D numerical model were built and are complementary for the design. Here we focus only on the physical model, and in particular on the flow measurement facility using UVP transducers.

2. Description of the physical model

2.1 Overview

The physical model has been built in accordance with the original civil drawings and actual latest laser measurements. The chosen geometric scale is 1/35, large enough to create the flow turbulence in the afterbay and in the tailrace while respecting the space restriction in the laboratory. The model's dimensions are approximatively 5x10 m^2 and its main components are (Figure 1):

1. Water supply from the pumping system of the lab, with the monitoring of the total discharge.
2. Two reservoirs for the distribution of the total discharge toward the four groups, with individual discharge control through electro-magnetic flowmeters.
3. Four turbine units, preceded by deflectors to give the flow the rotational speed observed at the turbine's outlet.
4. Fishway entries located on top of the afterbays' outlets. The discharge through those entries is controlled individually with rotameters.
5. Downstream connecting walls, at the end of which the bank fishway entries will be placed.
6. Tailrace channel
7. Restitution basin with a weir that controls the water level in the tailrace channel

2.2 Conception

The model has been first designed and assembled using CAD. Two materials have been used for the construction of the different parts. The afterbays, the body of the powerplant, the connecting walls and the fishways are made with PVC. The topography of the afterbay and the tailrace has been fixed with a 50mm thick concrete layer. The level of precision for each component of the model depends on the material it is made of: ± 1mm for the PVC parts and ± 5mm for the concrete parts.

2.3 Scale effect

The model is scaled in respect to the Froude similarity, meaning that the ratio between the inertial and gravity forces is preserved. This admits a same Froude number for both the prototype and the model. The Reynolds number has been found larger than $3.5x10^4$ for all discharges, with the consequence that the turbulence level is high enough to limit scale effects in the model [1].

2.4 Measuring devices and accuracy

To evaluate the flow in the model, velocities are measured in 3 directions with Ultrasound Velocity Profiler (UVP, Met-Flow SA). The UVP represents both a method and a device for measuring an instantaneous velocity profile in liquid flow by detecting the Doppler shift frequency of echoed ultrasound as a function of time and space [2]. The accuracy of the velocity measurements with the UVP reaches ±1mm/s, corresponding to a potential error of less

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than 1% of the mean velocity in the tailrace channel.

The UVP transducers are placed on a robotic traversing system (pointed by the red arrow on Figure 1, right) that allows to program automatic measurement sequences on a 2x2m^2 square. The robot itself can be moved on a frame that spans the model and that can be moved up and downstream on lateral rails. Thanks to this infrastructure, the measurement procedure is flexible and replicable.

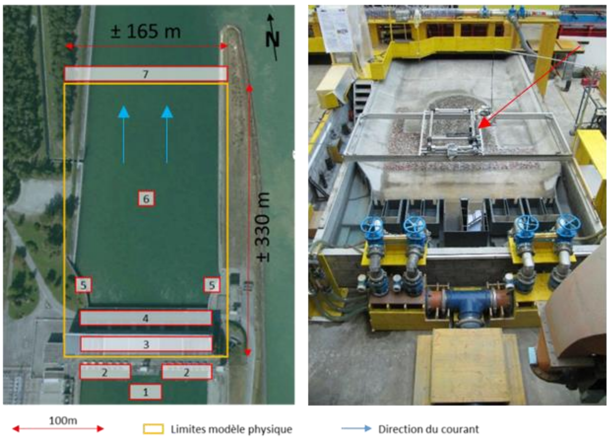

Figure 1: Left and middle – main components and dimensions of the physical model. Right – physical model in the laboratory. (Satellite background image: Google Earth)

2.5 Measurement procedure

Two transducer axes are used to create 2D representations of the measured flows. The robot on which they are mounted on moves automatically to cover the surface to be measured and also manages the triggering of the measurements at each new location. Three types of datasets are recorded with this system: surface flow (longitudinal and lateral velocities), sections across each fishway entry (longitudinal and vertical velocities) and temporal variations of the longitudinal jet velocities.

The UVP transducers measure at each location a velocity profile along the beam axis, with a resolution of 5.2mm (18cm in prototype). Each profile used for the results is an average of several profiles, the number being chosen by the user. For the surface and the cross-section flows, the number of profiles taken at each location was set to 512. For the analysis of the temporal variations of the jet X-velocities, this number was increased to 1024. In order to avoid the effect of the transducer on the local velocities, the measurement starts 10cm away from the transducer for the surface flow and 1cm for the subsurface flow.

The global resolution of the measurements depends on the largest distance between two robot locations. The precision was set in accordance to the project phases need. Therefore, two types of grids have been built: one for the validation of the model, with a mesh size of 100mm (Figure 2) and one for the analysis of the fishway entries, with a mesh size between 25 to 50mm (Figure 4). In total, 83’440 points were recorded for the surface flow validation of one single turbining configuration. It covers the whole width of the tailrace and the first 160m downstream of the powerplant. The 10 X-Z planes (Figure 3) represent 68’568 measured points, covering the whole depth and the first 160m downstream of the powerplant. Those numbers were increased to 122’000 (surface flow) and 38’000 (cross-sections) during the analysis of the fishway entries.

Each point is characterized by its spatial coordinates X, Y, Z and its associated velocity. At the end, the interpolation over the whole domain of the data of each transducer creates the velocity field.

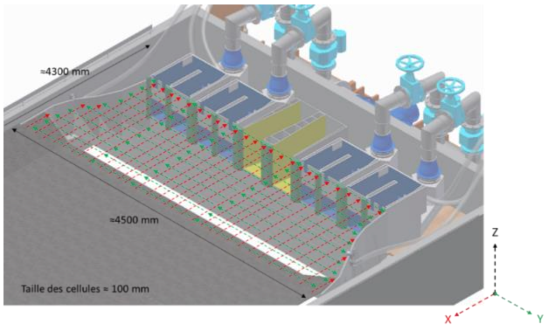

Figure 2: Schematic representation of the surface flow (X-Y plane) measurement procedure for the model validation.

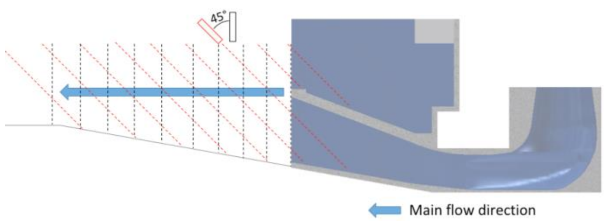

Figure 3: Schematic representation of the subsurface flow measurement procedure (X-Z planes). Cross-section through a fishway entry placed over the turbine draft tube.

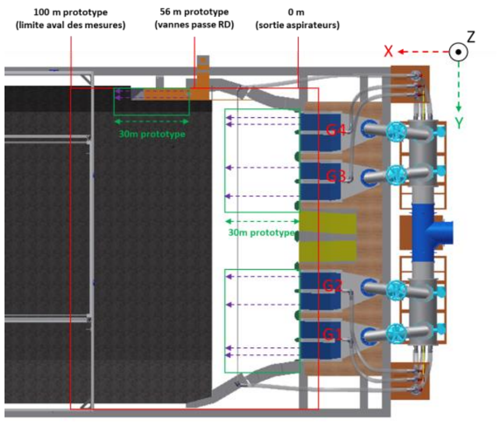

Figure 4: Schematic representation of the flow measurement procedure for the fishway entries analysis. In the red square: surface flow (X-Y plane) with a mesh size of 1.75m (prototype scale). In the green square: surface flow with a mesh size of 0.875m. Along the violet arrows: subsurface flow (X-Z planes) with a mesh size of 0.875m.

3. Validation of the model

Two types of information have been recorded on site: observations of the surface flow and ADCP (Acoustic Doppler Velocity Profiler) measurements of the subsurface. The same data were collected on the physical model according to the measurement procedure described before.

Four turbining configurations have been chosen to compare the results of the physical model with the on-site measurements. Figure 5 and Figure 6 presents the results for one of those four exploitation cases. The discharges turbined by group 1 to 4 are : 0, 0, 300 and 300m^3/s.

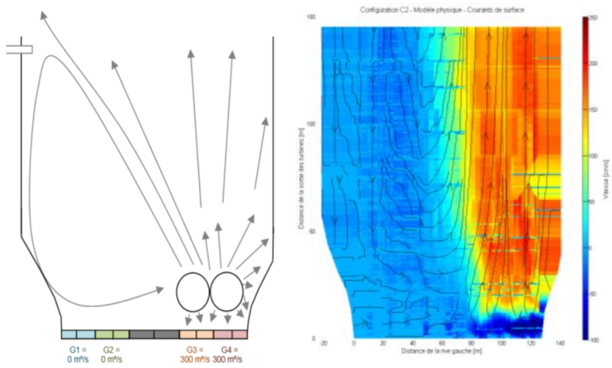

Figure 5: Exploitation case 2 – qualitative comparison of the observed surface flow patterns (left) and the one measured on the physical model (right). The colours correspond to the value of the X-velocity, from -100 (blue) to 200 cm/s (red).

Figure 5 (left) shows a large recirculation, well reproduced by the physical model, where the velocities range between -50 and 0cm/s. This recirculation seems to be larger on the physical model than in reality; the recirculation has been observed approximatively on the first 150m after the turbine outlets while on the physical model, it reaches the downstream end, corresponding to a distance of 280m. The positions of the resurgences are well represented by the model. However, one can observe a slight deviation of the turbulences toward the right bank on the physical model.

This deviation is also visible in the comparison of the subsurface flow at 50m from the exit of the afterbays (Figure 6). However, the physical model shows good velocity magnitude in front of groups 3 and 4 and along the right bank. On the other side of the model, the recirculation shows velocities closer to zero than in reality.

The validation of the physical model with all 4 exploitation cases has shown that the model is able to represent appropriately the flow field occurring on site, both for surface and cross-profile flows. The turbulences and resurgences observed on site can also be observed on the model with precise longitudinal positions. In contrast, the lateral positions of the jets and main resurgences is systematically deviated 5 to 10 meters toward the right bank, independently of the group used. Also, the lateral spreading of the jets is higher than in reality. As all groups have been built after the same construction drawings, this deviation is likely to be a consequence of the design, creating a preferential path in the right afterbay. Globally, the physical model creates trustfully the flow in the afterbays and in the tailrace channel.

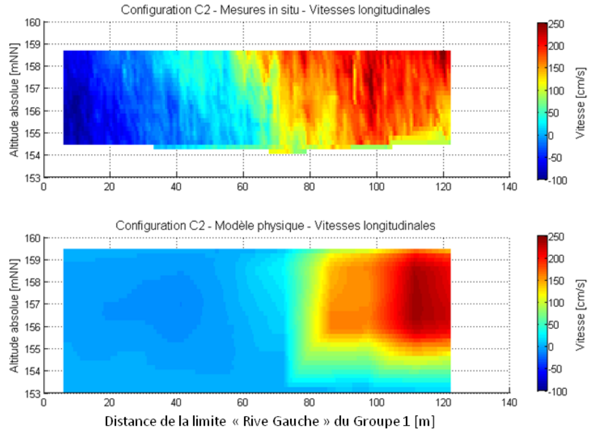

Figure 6: Exploitation case 2 – mean velocity field at 50m from the exit of the afterbays. On-site measurements are on top, and the physical model situation at the bottom. The colors represent the magnitude of the longitudinal velocity from -100 to 250 cm/s.

4. Analysis of the fishway entries

After the validation phase, the fishway entries have been installed on the model. 8 entries are located at the top of the afterbays outlet and 4 are placed 30 to 55m downstream in the left and right banks. The objective of the lateral entries is to guaranty the visibility of the fishway entrance even for high turbined discharges. A design optimization was needed to assure their hydraulic efficiency.

4.1 Test exploitation cases and inlet conditions

The functionality of the fishway has to be guaranty up to discharges of 1'400m^3/s (installed capacity). Nine exploitation cases have been chosen to test the behavior of the fishway entries, covering a range of turbined discharges between 600 and 1'400m^3/s. For the purpose of this article, one exploitation case, a medium total discharge unequally divided between the groups has been selected. The exact distribution is presented in Table 1. The discharge injected through the fishway entries is constant and equal to 5m^3/s. 1 entry is composed of two slice gates, so 2.5m^3/s per gate. The elevation of the gate was adapted to the downstream water level (which depends on the turbined discharge) to keep a constant drop of 30cm. This drop creates a jet with velocities around 2m/s.

Table 1: Exploitation case Q900 to test the behavior of the fishway entries

Case	Q_{total} [m^3/s]	G1 [m^3/s]	G2 [m^3/s]	G3 [m^3/s]	G4 [m^3/s]
Q900	900	350	350	0	200

4.2 Temporal analysis of one entry

The first observations of the fishway entries behavior rapidly show that the visibility of an entry jet depends mostly of the discharge turbined by the group where the entry is located on. Therefore, a systematic temporal jet analysis has been conducted on the right-bank entry of group 4 (see Figure 4), while changing the turbined discharge from 200 to 350m^3/s with steps of 50m^3/s. Figure 7 shows the longitudinal velocities of the jet 0.5m below the water surface for a zero discharge of group 4 and 350m^3/s (maximal discharge). The velocity at each point along the beam axis has been measured 1024 times, representing measurement duration of 5'30'' at prototype scale.

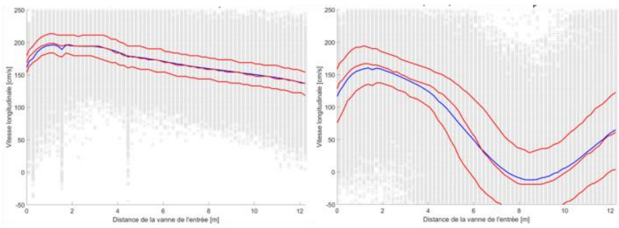

Figure 7: Temporal analysis of the jet longitudinal velocities (cm/s) in function of the distance to the fishway entry gate. Left: the group under the entry is stopped. Right: the group turbines the maximal discharge (350m^3/s).

If group 4 is stopped, the jet of the fishway entry is clearly visible, with average velocities above 150cm/s up to 12m downstream of the entry gate. In addition, the difference between the quartiles 25% and 75% is almost constant, around 35cm/s. With a turbined discharge of 350m^3/s, the behavior of the jet is completely different. The turbulences created by the turbined water confine the evolution of the jet in the tailrace channel and increase the velocity variations. Already 8m after the gate, the mean jet velocity is close to 0cm/s and the difference between the quartiles 25 and 75% at the same distance is above 100cm/s. This clearly shows that the fishway entry is no longer visible for the fish.

4.3 Flow analysis

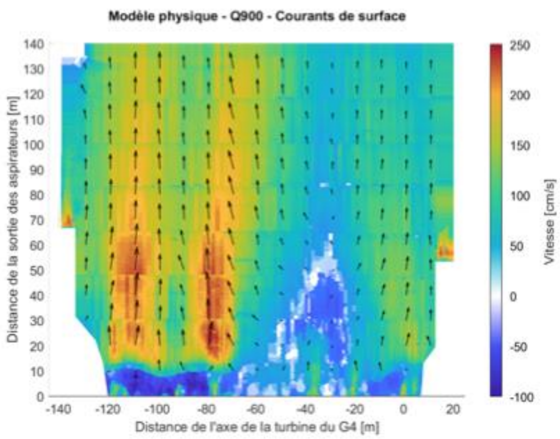

Figure 8: Surface average flow (X-Y plane) for the exploitation case Q900 (see Table 1).

The analysis of the surface flow of the exploitation case Q900 (see Table 1) shows that in front of group 1 and 2, turbining the maximal discharge, the highest velocities are between 200 and 250cm/s, while the minimal velocities approach -50cm/s in the 10 first meters after the turbines outlets. Those negative velocities are related to the high turbulences created by the turbined flow. As a consequence, the development of the jet coming from the fishway entries of those two groups is rapidly blocked. This observation corresponds to the results of the systematic analysis of the jet velocities presented in the preceding chapter. In front of group 3 (stopped), the longitudinal velocities in the tailrace channel are small, allowing the expansion of the jets up to 30m. In front of group 4, turbining 200m^3/s, this expansion reaches 10m, before the jets vanish in the global flow. The same conclusions can be drawn by observing the cross-sections across a fishway entry of group 1 and an entry of group 4.

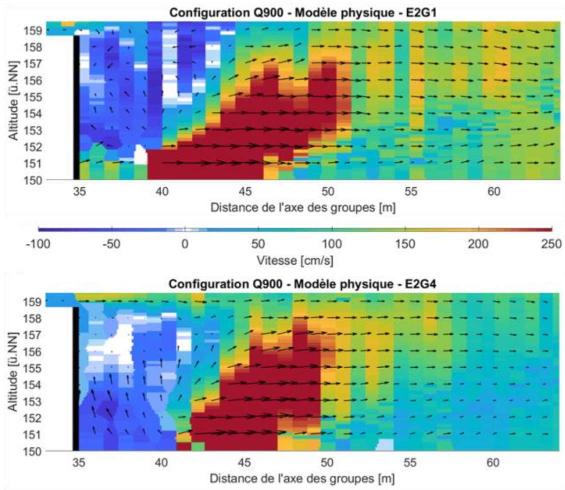

Figure 9: Subsurface average flows (X-Z planes) across one fishway entry of group 1 (turbined discharge 350m^3/s) and one of group 4 (turbined discharge 200m^3/s).

5. Conclusion

With the help of the UVP technology, it was possible to evaluate and optimize the fishway entries on the physical model of the Rhinau Hydropower plant. Installed on a robot, the measuring system allowed a flexible and replicable procedure, as it was required to compare the 2D flow fields for different exploitation cases. The validation of the model with measurements taken on site has confirmed the agreement of the physical model with the prototype and the accuracy of the measurements with the UVP. Even if small echoes issues have been observed in the measured data, in particular near the model borders, leading to a local loss of information, the global and interpolated results showed truthfully the flow field in the afterbays and in the tailrace channel.

References

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References

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