Control of turbulent flow in vertical slot fishways for the migration of small fish species

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CONTROL OF TURBULENT FLOW IN VERTICAL SLOT FISHWAYS FOR THE MIGRATION OF SMALL FISH SPECIES

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INTRODUCTION

The improvement of devices that allow the upstream migration of fishes through engineering constructions or natural obstructions in rivers is now a real priority to maintain the biodiversity. Vertical slot fishways are commonly used and are very effective in ensuring unhindered passage of the species of large size fishes. The flows within these hydraulic structures are turbulent and present unsteady vortex dynamic in relation to the geometric parameters of the pools (slopes, flow discharges and pool widths) (Puertas [], Rajaratnam [], Wu []). The modes of locomotion of the fish depend to the species and are the object of several recent studies from the fluid mechanics community (Triantafyllou []). The fishes use the fluid motion generated inside the pools to the propulsion and to move easily upstream in the fishway. Nerveless the species with small sizes have some difficulties to upstream migrate because the kinematic energy and the velocity are too large for them. An experimental study is undertaken to characterize the turbulent flow for various configurations of vertical slot fishways and to determine how their characteristics might be modified in order to facilitate the passage of small species. Particle Image Velocimetry is achieved to analyze the effects of vertical cylinders within the pools on the dimensions of recirculation zones and the turbulence intensity. Mean velocity and fluctuation measurements inside a pool with and without cylinder are compared. The efficiency of these adjunctions is evaluated by experiments with small salmonides. Tests of upstream migration are recorded and analysed to better understand the behaviours of the fishes inside the pool.

EXPERIMENTAL SET-UP

A physical model, related to the prototype by the Froudian similitude, of geometrical scale ¼ is used for this experimental study. This model has average characteristics of several vertical slot fishways built in France. The velocity scale is 1/2 and the discharge scale is 1/32. The width of the slot is b = 0.075 m. The vertical slot fishway model consists of five pools, L = 0.75 m long and H = 0.55 m deep (Figure 1).

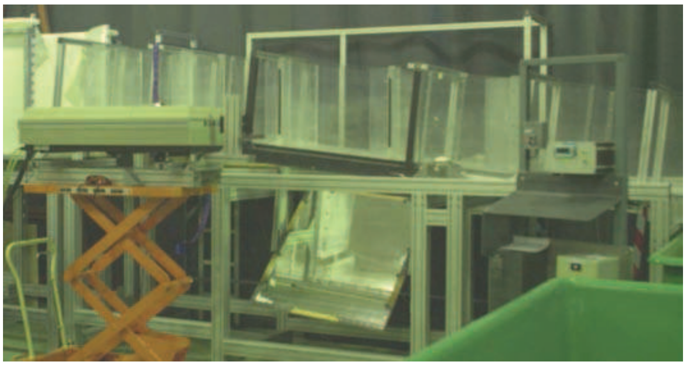


Figure 1 – Experimental device

The width of each pool has been limited to two values: B = 0.675 and 0.50m (Figure 2) which correspond to the full scale to 2.7 and 2m. The channel slope has been chosen to 10%. The flow discharges has been fixed to Q=23 L/s which corresponds to a flow discharges to 736 L/s at the scale 1. The model discharge velocity in the slot is V_d = 0.94 m/s according to this slope . The equivalent Reynolds number, calculated with the slot width b and the discharge velocities in the slot V_d is Re= 79100 and the Froude number $F_r = \frac{V}{\sqrt{gZ_0}}$ = 0.026 with Z_0 the water level difference between two successive pools.

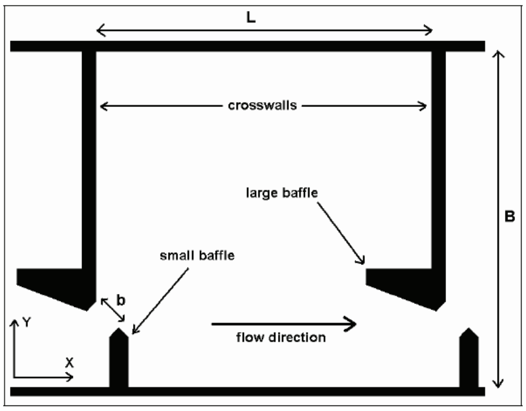


Figure 2 - Pool configuration

The experimental measurements were taken in the third pool in order to ensure an established symmetrical flow. The X-axis is in the longitudinal direction and the Y-axis is in the transverse direction of the fishway. The XY plane is parallel to the channel bed. All the geometric dimensions are multiplied by 4 to obtain the full scale and the velocities are multiplied by 2 to have the full scale or are normalized by the discharge velocities in the slot Vd. The full scale is significant for this application to rely the velocity and the capacities of the fish for the locomotion. The cylinder placed in the pool has a diameter of one slot and its center is placed at X = 2.1b and Y = 3.1b. Such a location of the cylinder significantly influenced the flow pattern by deviating the jet and shear layer and reducing the recirculation currents.

Velocity measurements were taken by means of Particle Image Velocimetry (PIV) in one plane parallel to the channel bed of the fishway (Z=15 cm). The acquisition and treatment PIV system is composed of a laser lighting a flow section, a camera system and a synchronization system. The HIRIS 2.1 software allows synchronizing the laser and the cameras. A laser Nd-Yag double cavity Spectra-Physics (2x180 mJ) has been used to highlight a flow section seeded by hollow glass particles of 11 µm diameter. The frequency of each cavity is 10 Hz and the wavelength is 532 nm. The beams coming from the two cavities are directed towards a system of double lens system making it possible to produce narrow laser sheets which have a thickness of about 1.5 mm. In order to record the successive images of the flow, two cameras JAI are used with objectives of 50 mm and placed in parallel to visualize the whole pool. The resolution of these cameras is 1600x1200 pixels², coded on 8 bits. The cameras make it possible to acquire two successive images of the flow separated by a very short time Δt (between 3000 and 4000 µs) which is generated between the two cavities of the laser. Davis 7.2 software (Lavision) computes cross-correlation between the successive images and postprocessing on the calculated data. An initial interrogation area of 64x64 pixels, a final interrogation area of 32x32 pixels with an overlap of 50 % and window deformation are used to compute the cross-correlation. For each camera, 1000 double image acquisitions (separated by T = 100 ms) allow to obtain 1000 instantaneous velocity fields. At each time, the two velocity fields calculated are jointed in order to have the complete velocity field of the pool. Statistics as mean, root mean square or spatio-temporal correlation are calculated. Velocity amplitude, vorticity, streamlines are also extracted to follow the fluid motion and their topologies.

RESULTS

The flow with and without cylinder has been studied for the two typical widths of the pool B=2.7 m and B=2m (L. Tarrade et al., 2008). The characteristics of the mean flow are considered, particulary the mean velocity, the root mean squares of the different components, the turbulent intensity and the streamlines (Figure 3). For the two configurations with and without cylinder, the flow in a pool is mainly composed of three important areas: a principal jet produced by the slot, passing through the pool with decreasing velocity and two large recirculation zones generated on each side of this principal flow. Recirculation around an axis perpendicular to the channel bed allow for dissipation of the jet energy in each pool. Swirling cells of variable sizes, created by the principal recirculation, occur in all the corners of the pool, due to the velocity differential between the recirculation flow and the zero velocities on the wall. Two different flow patterns occur according to the ratio length/width of the pool.

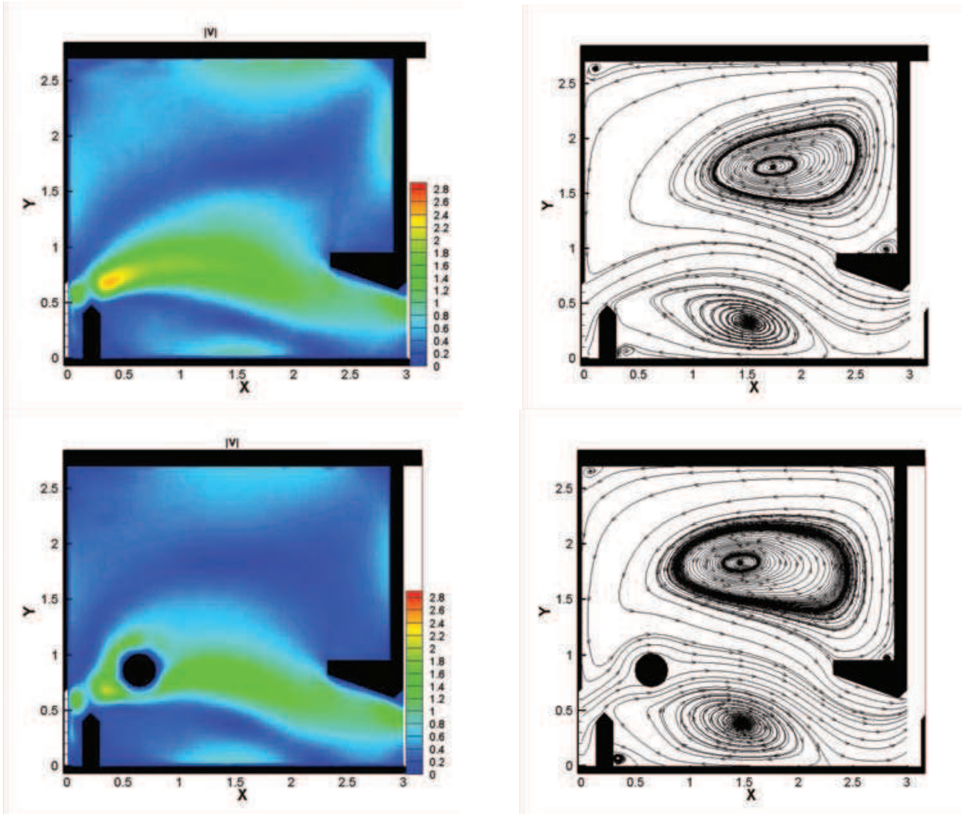


Figure 3 – Velocity amplitude and streamlines for I=10%, B=2.7m
without and with one cylinder

The first flow pattern occurs for the largest width (B=2.7m) with and without the cylinder. The principal flow leaving the slot enters the pool as a curved jet which opens out before converging towards the following slot []. The jet creates on a side, between the large baffles, an important recirculation area occupying roughly half of the pool surface. On the other side of the principal flow, a swirling zone of smaller size, rotating in the opposite sense to the preceding one, is generated between the small wall deflectors. The highest velocities are found in the jet, reaching a maximum when leaving the slot and decreasing progressively as the flow enters the pool while the lowest values are found in the recirculation areas. The great difference between the configuration without and with the cylinder is a small curvature of the jet around the cylinder which favors the penetration of the jet in the top part of the pool. The main vortex stays more along the horizontal axe and globally the mean amplitude velocity is reduced in the whole pool.

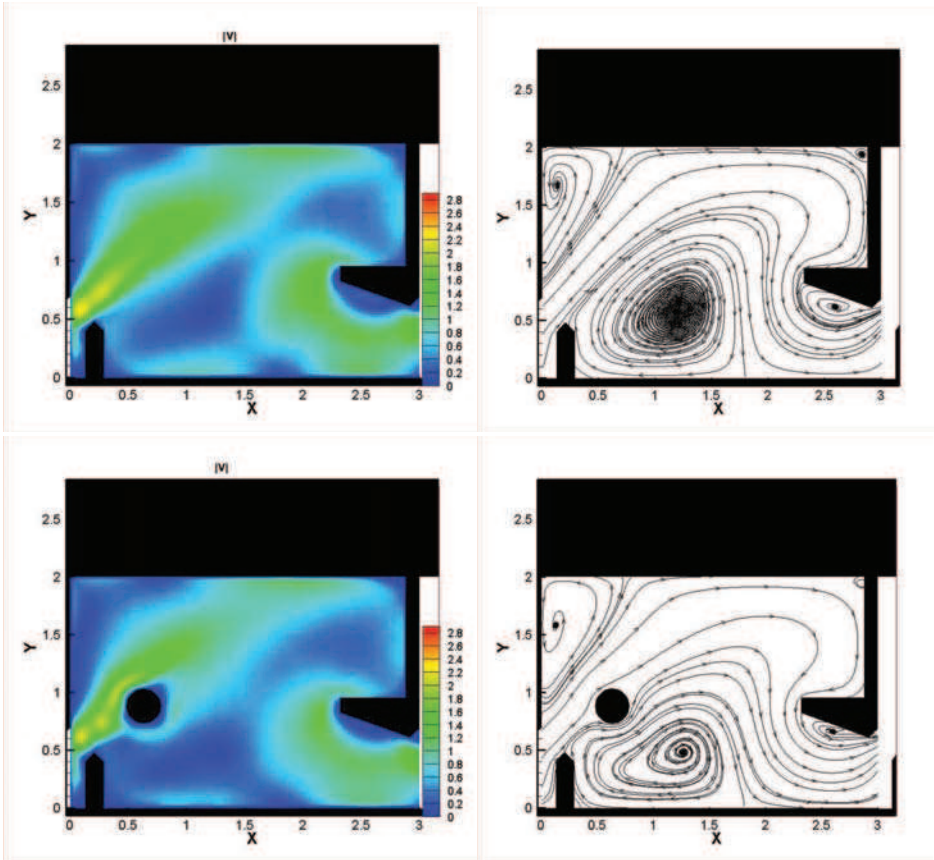
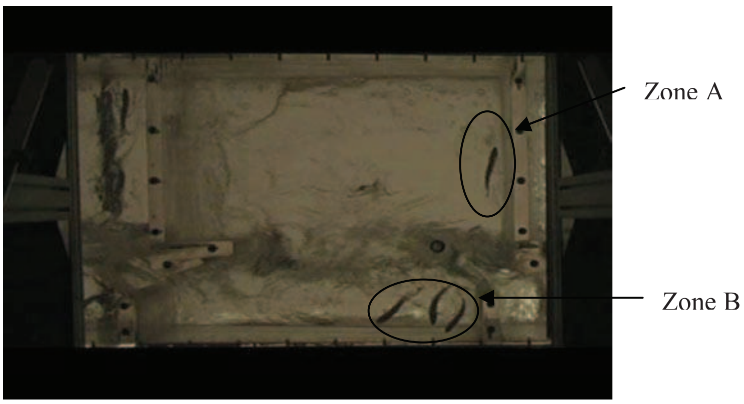


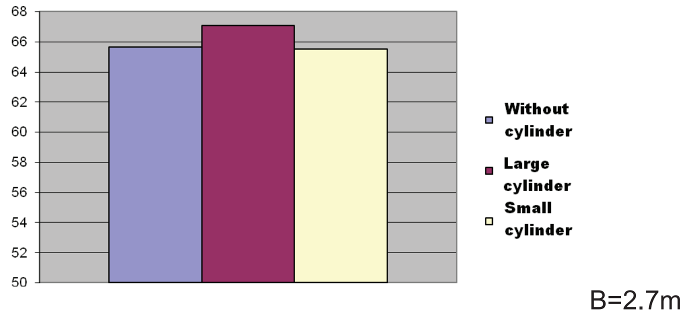
Figure 4 – Velocity amplitude and streamlines for I=10%, B=2 m
without and with one cylinder

A second flow pattern occurs for the pools of the low width (*B*=2m): the jet has a very curved form and directly hits the opposite side wall (Figure 4). Two large contra-rotating swirls are then generated in the corner upstream of the pool and in the convex part of the jet and a smaller one occurs close to the large baffle. The reduction in width of the pool changes the dimensions and the shapes of the swirling cells: the area of principal recirculation occurring for the first flow pattern is divided into two small swirls. The first is moved towards the upstream corner of the pool with a reduction of its surface area compared to the first pattern and the second is pushed back along the large deflector. On the other side of the flow, the vortex tends to occupy the open space left in the convex part of the curved jet. It contracts in the longitudinal direction and is stretched in the transverse direction. Its size relative to the pool surface area increases. The velocities are high in the principal flow, reaching a maximum in the slot, while the values are low in the centre of the large swirls, creating zones of strong velocity gradients on the edges of the jet (Figure 3 and Figure 4). The effect of the cylinder is an early deviation of the jet in the bottom part of the pool and a small reduction of the vortex installed in the convex part of the flow close to the small baffle. The velocity amplitude seems to decrease also for this configuration with the adjunction of a cylinder. The turbulent kinetic energy is globally reduced in the pool for the two widths with the adjunction of a cylinder but, close to the cylinder, the velocity variation reaches a peak of intensity. Close to the large baffle the TKE is reduced and it is the same for the two widths. The flow characteristics become more acceptable for the swim capacities of the small fish and the swirl created downstream from the cylinders provides rest area.

VALIDATION WITH FISHES

The validation of the efficiency of this adjunction in a fishway has been tested with small fishes. Fario trouts with a range of 8cm-10cm length have been used to test different configurations without cylinder and with cylinder of one slot diameter (large cylinder) or 30% of one slot diameter (small cylinder) for the two different widths of the pools. The experimental conditions (temperature, light, flow rate) are controlled and reproducible to eliminate hazardous conclusions. The different tests have been carried out in different orders to be sure that the evolution of the behavior of the fishes didn't influence the final results. Two sets of one hundred fishes have been presented by groups of thirty in the last pool of the fishway to study the behavior of the fishes and to count the number of fishes able to upstream migrate inside the fishway. The trajectories of the fishes and the rest zones they used are recorded by a camera place below the third pool of the fishway.





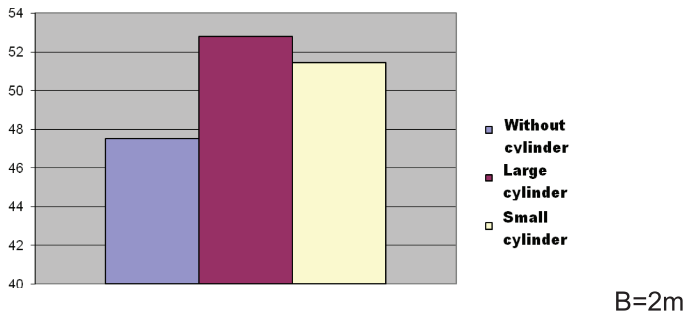


Figure 5 – Velocity amplitude and streamlines for I=10%, B=2 m without and with one cylinder

SUMMARY AND CONCLUSIONS

REFERENCES

[] Puertas, J.; Pena, L.; Teijeiro, T. 2004. An experimental approach to the hydraulics of vertical slot fishways. Journal of Hydraulic Engineering 130 (1): 10-23.

[] Rajaratnam, N. ; Katopodis, C.; Solanki, S. 1992. New designs for vertical slot fishways Journal of Hydraulic Engineering 19 (3): 402-414.

[] Wu, S.; Rajaratnam, N.; Katpodis, C. 1999. Structure of flow in vertical slot fishway. Journal of Hydraulic Engineering 125 (4): 351-360.

[] Triantafyllou M., 2007: Special issue: Animal locomotion: The hydrodynamics of swimming. Experiments in Fluids Volume 43, 5.

[] Tarrade L., Texier A., David L., Larinier M., 2008. Topologies and measurements of turbulent flow in vertical slot fishways. Hydrobiologia 609:177–188.

[] Tarrade L., Texier A., David L., Larinier M., 2007. An experimental study of turbulent flow in vertical slot fishways: adaptation to the small fish species.6th International Symposium on Ecohydraulics (Nouvelle Zélande).