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OPTIMIZATION OF FISH PASS ENTRANCE LOCATION AT A HYDROPOWER PLANT CONSIDERING SITE-SPECIFIC CONSTRAINTS

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ABSTRACT

Hydropower plant operators have to comply with the current legislation. More specifically, the European Water Framework Directive brought major changes within recent years. To be able to achieve the required “good ecological potential” the river continuum has to be restored. Fish passes play a central role in river restoration in order to recover the passability. The attraction of the fish pass plays an important role in establishing a new fish pass. If the fish pass is not connected to the main flow properly, fishes may have difficulties to find the entrance. There are design rules and general recommendations to assure the attraction of the fish pass, however site constraints may prevent their application.

In order to find the best solution, a two-stage procedure is chosen. At the first stage a preliminary study is conducted, performing simplified hydraulic computations. Thus a preferred entrance location can be identified more easily. At the second stage, the preferred entrance location is optimized for the given situation. Therefore different attractions concepts are investigated. To assess the fish pass attraction the migration corridor is determined using the velocity field. It can be visualized by filtering out the rheoactive velocity range of the migration corridor. Thus a reasonable entrance configuration can be found under unfavorable conditions.

Keywords: fish pass, attraction flow, migration corridor, European Water Framework Directive

1. Introduction

Hydropower plant operators in Europe have to fulfil the current legislation especially if they reapply for a concession for their hydropower plants. The European Water Framework Directive aims to achieve a “good ecological potential” of surface water bodies (Richtlinie 2000/60/EG). Herein the ecological passability plays an important role, which is obviously interrupted by hydropower plants. That is why the hydropower plant operators are anxious to restore the ecological passability by installing fishways. Sometimes site restrictions impede the best practice solutions. This paper shows a methodology how to optimize the fish pass attraction under unfavourable conditions.

1.1. Case specifications and boundary conditions

Most of the fish species demand on the possibility to migrate through rivers in order to ensure the survival of their offspring. If the migration correspond with the spawning time, the fish will show a clearly recognisable behaviour pattern: a rheoactive swimming behaviour, which means they will align along the flow direction and try to swim against. (Regelwerk DWA-M 509; Pavlov 1989). There is a broad variety of orientation mechanism (optical, tactile, lateral line organ, hearing, temperature, smell) the fish use. Nevertheless, it was observed that the fish will move in a migration corridor, where they can find their rheoactive velocity (Schmutz, Mielach 2013). At the river Iller the trout can be determined as near-surface swimmer (approx. 1 m beneath the water surface) and the barbell as near-bed swimmer (few centimeters above the river bed). In literature their rheoactive velocities are: for the trout 0.15 m/s (Adam, Schwevers 1997) and for the barbell 0.20 m/s (Adam *et al*. 1999). Investigations of Pavlov (Pavlov *et al*. 2000) and

Lupandin (Lupandin 2005) show: the higher the turbulence, the lower the swimming performance, as the fish have to use their stabilizing fins. These fins increase the hydraulic resistance, hence there is less energy available for movement. At a critical turbulence value, which depends on the fish length, a significant decrease of the swimming performance will occur. Lupandin stated: if the vortex size is 2/3 of the fish length, a significant loss in fish swimming performance will occur (Lupandin 2005). Hence the fish try to avoid areas of high turbulence and dead water (smaller than the rheoactive velocity).

1.2. Location of fish pass entrance

During the spawning season the fish migrate upstream till they reach a hydraulic or structural barrier. They try to overcome the barrier, whereas some species show a quite high persistent perseverance to overcome the obstruction. This may cause a certain delay, stress or injuries (Larinier 2002a; Regelwerk DWA-M 509). There are some construction recommendations of Larinier in order to assure an appropriate fish pass attraction e. g. the fish pass should be located near the riverbank and as close as possible to the barrier. Thus the fish won't miss the entrance. The entrance neither be placed in areas of high turbulence, nor in recirculating zone, nor dead water zones (Larinier 2002b). For hydropower plants the discharge ratio between the fish pass and the turbines has to be sufficient, Larinier recommends 1 to 5 %. Due to site constrains (underground, flood protection, sediment management, maintenance) it is sometimes not possible to place the entrance at the optimal position. If this is the case, a greater discharge may help to improve the weak attraction (Larinier 2002b). A comparison of attraction and passage efficiency between various types of fishway has shown, that on the one hand the attraction of a vertical slot passage is slightly advantageous, on the other hand the passage efficiency of a nature-like fish way is slightly superior (Bunt *et al*. 2012).

2. General site description and preliminary study

The study site is located at the river Iller in Southern Germany. A preliminary study was conducted in order to identify the best entrance location for the new fish pass. In collaboration with the design engineers three possible fish pass entrance locations (see figure 1) have been identified.

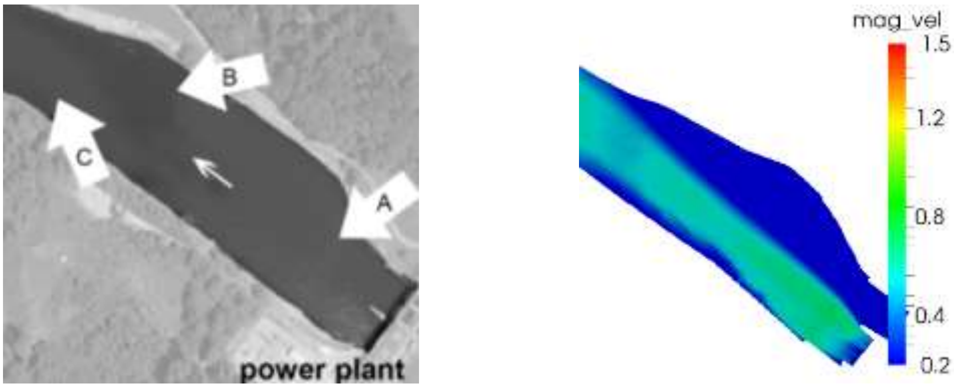

Figure 1: Possible fish pass entrance location for the preliminary study (left); velocity field for the current situation at mean discharge (right)

Position A is located closest to the power plant but opposite to the power house. Position B is placed close to the river bed contraction, at the end of the dead water zone. The position C is located on the orographic left-hand side approx. 250 m downstream of the power house. Within the scope of the preliminary study the exact fish pass geometry was not modelled. For simplification only a source term has been added, considering the position, direction, size and hydraulic discharge (set to 1 m^3/s) of the fish pass. At position B a connection between the migration corridor and the fish pass entrance will show up, although it is quite limited. At position A it is not possible to guarantee the perceptibility. Whereas at position C there will be a good connectivity. Hence position C will be investigated more in detail.

3. Simulations

All performed simulations are conducted with FLOW-3D (Flow Science), a commercial CFD software package, whose special techniques allow to capture the free surface of an open channel flow precise. The model domain is discretised uniformly in all spatial directions, with an edged length of 0.5 m. For the computations a Reynold Averaged Navier-Stokes model (RANS-model) is used in order to get appropriate computing times. As turbulence model the k-ϵ-model is used, whose implementations follows Harlow (Harlow 1967). Hence, the small scale turbulence are handled in a simplified way, solving two additional equations, one for the turbulent kinetic energy k and one for the energy dissipation ϵ. Out of this, the volumetric power density of the turbulent kinetic energy $\phi_{tke} = k \cdot 1/s \cdot \rho_w \; in \; [W/m^3]$ and the volumetric power density of the energy dissipation $\phi_{diss} = \epsilon \cdot \rho_w \; in \; [W/m^3]$ can be determined. These values should help in the discussions with fish experts, as the fish pass design is based on the maximum volumetric power density of the energy dissipation $[W/m^3]$, too. Nevertheless the evaluation of the volumetric power densities has to be handled carefully, as the k-epsilon model is quite mesh sensitive. For each entrance configuration a minimal environmental flow as well as the mean discharge scenario are conducted. As downstream boundary condition a virtual weir is used, which was calibrated applying the downstream rating curve. Source terms are used to model the turbine discharge. In order to be able to reproduce discharge distribution over the turbines correctly, the source terms are adapted to the size of the suction pipe an impinged with turbine discharge. The fish pass are supplied with a source term too, which is placed in the undermost fish pass pool.

3.1. Entrance configurations

The fishway is constructed as a nature-like fish pass supplemented with a groyne in order to improve the attraction to the entrance location. The proposed groyne is about 12 m long, measured from the left river bank. The groyne axis is aligned at 80 degree to the main flow direction (see Figure 2 – C1). For configuration C2 the groyne axis is slightly more inclined (70 degree to the main flow direction) as well as the groyne length is set to 13.5 m. The concept of configuration C1 and C2 tries to utilize the main flow to be a part of the attraction flow. Thus, the groynes should enhance the connectivity and the fish will likely find the entrance more easily. On the other hand the concept of configuration C3 and C4 aims to induce a shear zone with high turbulence, which should acts as hydraulic barrier. Therefore the entrance is sited downstream of the groyne (see Figure 2 – C3 and C4). The groyne of configuration C3 is about 10 m long (measured from right wall of the fishway) and gently smoothed with a tangential inclination of 60 degree. Configuration C4 is 13.5 m long and also gently smoothed with a tangential inclination of 70 degree.

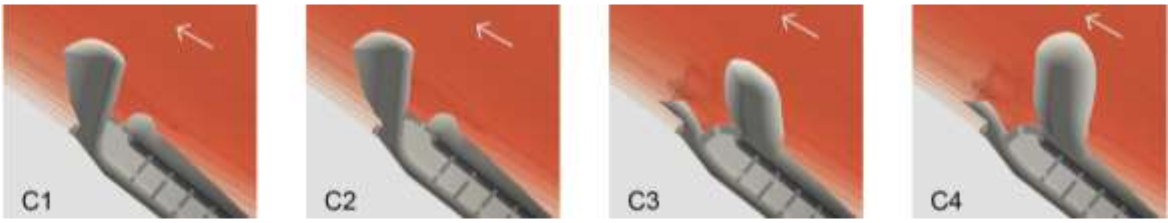

Figure 2: Entrance configurations embedded into the riverbed

3.2. Migration corridors

In order to achieve a reliable assessment of the entrance location the migration corridors will be evaluated. Therefore the simulated velocity fields are filtered by the rheoactive velocity range. For visualization purposes: all cells with a velocity magnitude out of the rheoactive velocity range are blanked out (see Figure 3). Hence, if there is a visible connection between the main channel and the fish pass, the fish likely find the fish pass entrance. The configurations C3 and C4 won’t be able to form up a connection to the main migration corridor, thus the fish will very likely miss the entrance. The configurations C1 and C2 are much better connected to the main channel, although the velocity field in front of the fish pass entrances are quite slow, too. At a higher discharge the configuration C1 is prone to be submerged, which may harm the attraction. The configuration C2 will perform better under high discharge conditions as it is more streamlined compared to C1. The groyne obviously contracts the riverbed as well as the migration corridor. It can be concluded, the greater the contraction of the riverbed, the weaker the connectivity.

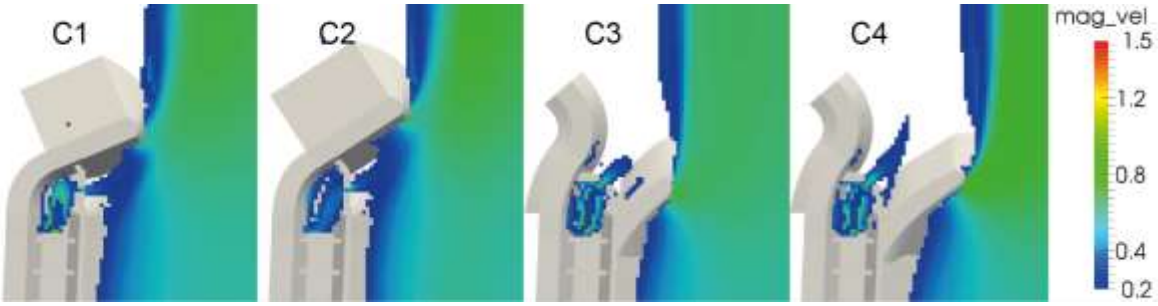

Figure 3: Migration corridors - filtered velocity fields (0.2 – 1.5 m/s), mean discharge

3.3. General remarks

The volumetric power density field of the turbulent kinetic energy shows that the turbulent kinematic energy is quite low. Compared to the fish pass design rules, the volumetric power density is about 10 to 20 times smaller. Hence, no hydraulic barrier will form up in the present circumstances. Within the low flow conditions the fish pass become more dominant as the competitive flow is increased to 10 % of the total discharge. Hence, the migration corridor is well connected to the fish pass entrance.

4. Conclusions

Different entrance locations have been observed to find the best solution under unfavorable conditions. To optimize the fish pass entrance the flow fields are computed. Based on that, the migration corridors were determined. The idea to use a hydraulic barrier, which is avoided by the fish, was proven to be an inadequate solution. In contrast, migration corridor shows up clearly under low flow conditions. Based on these results, the fish pass will be constructed. Furthermore, within the next years it will be tested whether the modeled flow conditions will appear in nature and the fish will find the entrance in a satisfactory manner.

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