Flexible Fish Fences

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Introduction

Hydropower is a very important and well established renewable energy source especially in alpine regions. Since the aim of climate protection is politically implemented, further expansion of hydropower is promoted by the federal states and communities. But along with the progress of hydropower a great conflict arises with the implementation of the European Water Framework Directive with reference to the “good ecological status”. Interrupted longitudinal continuity leads to a change of habitat for rheophil species. Thus connectivity for migrating organisms has to be ensured within the design and construction of new hydro power projects. A variety of functional facilities were developed to help to maintain the upstream migration of fish; guidelines for the design exist. Bigger problems emerge with the realization of the downstream migration at hydroelectric power plants. The latest technology still does not provide efficient solutions that are simultaneously profitable for power plant operators. In order to guarantee downstream fish migration, all target species in all target stages of growth have to be protected from injuries and mortality caused by turbine entrainment and be guided into a bypass. The most promising fish protection systems are mechanical barriers, especially vertical and horizontal bar racks, which deflect fish physically from the turbine intake. Clear widths between bars are measured by the body dimensions of fish and depend on the target species in the target stage of growth that have to be protected. The requirements on maximum clear width of fish protection racks are varying widely dependent on the regional regulations. In some federal states in Germany maximum clear distances of 20 mm are standardized for small hydropower plants. (Dumont, 2005) For medium and large run-of-river power plants the implementation of such fine screens is not practicable in most cases. Enormous amounts of steel and a complex thrash rack cleaning system are required, which result in high investment and operational costs. Additionally high hydraulic losses reduce the energy production due to a high degree of structure.

The flexible fish fence was developed at the Unit of Hydraulic Engineering, University of Innsbruck, in the context of designing a fish protection facility for an overflowed “river flow power plant” (Brinkmeier & Aufleger, 2011). Horizontally arranged steel cables are installed upstream of the turbine intakes and block fish from the turbine entrainment – depending on their permeability - physically or by a behavioural effect. During higher discharges, when turbines are put out of operation and a big amount of floating matter is transported by the stream, the cables are released and thus lying on the river bed. This prevents the clogging of the surface area during flood events and has the added advantage that the entire cross section is available for discharge, floating matter and bed load. Besides the application at overflowed power plants, the flexible fish fence is also practicable for the ecological upgrading of existing power plants or conventional run-of-river plants, if additional technology upgrades are made.

1. Progress of development

1.1 Motivation

Hydroelectric power plants pose an interruption to river continuity and thus to fish migration, which is essential for the preservation of fish population. During the course of a current draft of an overflowed “river flow power plant”, the subject of fish protection and downstream migration came to light. A lack of existing efficient and practicable techniques applicable to medium and large run-of-river-plants still exists. According to first evaluations of hydrobiologists the previous design of a vertical bar screen situated in front of the turbine intakes and positioned at an angle of 30° with a clear width between bars of 30 mm did not meet the current standard of fish protection facilities. A further reduction of the clear width was not possible due to the required complex cleaning system. Subsequently, considerations about an alternative fish protection concept were initiated, resulting in the concept of a flexible fish fence.

The first experiments were performed in the hydraulic laboratory of the University of Innsbruck to demonstrate the general functionality of the new fish protection concept. Thereby the different modes of operation and the characteristics of the steel cables regarding sag and oscillations were examined under various flow conditions. Additional test series were performed to simulate the scenario of driftwood jams in case of higher discharges. In cooperation with a mechanical engineering company a concept for the technical realization of the flexible fish fence was developed. An overall approach was developed and applied in the planning of overflowed “river flow power plants” considering technical and biological factors, which have an influence on fish protection and guidance efficiency.

1.2 Technical and biological basics of fish protection systems

The challenge of a fish protection facility is to prevent fish from being entrained into turbine intakes and to guide them into a bypass (Larnier & Travade, 2002; Ebel, 2013). Various different systems exist, but all of them vary widely regarding their effectiveness. Mechanical barriers, especially vertical or horizontal bar screens, are state of the art techniques for small hydroelectric power plants in Europe.

Behavioural barriers are based on the effect of visual, acoustic, hydrodynamic or electrical stimuli on fish behaviour without any mechanical device. By generating an artificial stimulus fish can either be repelled from the turbine intakes or attracted to a bypass (Larnier & Travade, 2002; DWA, 2005). All technologies were tested by a number of laboratory and field studies, resulting in a great variance between field and laboratory measurements (DWA, 2005). The main reasons are different site parameters, which have a great influence on the efficiency. Lighting conditions (e.g. daytime, turbidity), water temperature and especially hydrodynamic conditions (flow velocity) strongly affect the intensity of perception (DWA, 2005). A crucial condition for the efficiency of behaviour influencing stimuli is that fish can detect the stimuli and furthermore have enough time to react (Lehmann, 2011).

Although behavioural barriers are currently not used in the hydro power sector, the effect of a stimulus like light or electric impulses could be useful in respect of a combination with the flexible fish fence and may be an option for improving fish protection or fish guiding efficiency.

Within the design and application of the flexible fish fence geometrical and biological factors, which have a significant effect on the fish protection and guiding efficiency, were considered. For this pre-examination the geometry of the flexible fish fence was chosen as a horizontal bar screen. In comparison to conventional screens with vertical bars, horizontal screens with the same clear width offer better fish protection. This is due to the fact that fish normally do not change their natural swimming position (Holzner & Blankenburg, 2009). Thus clearance of the bars can be adapted to the body height, which is commonly greater than the body width, especially with alpine fish. Moreover, the risk of injuries through contact with the bars of the facility is lesser in comparison to vertical thrash rack systems (Ebel, 2013; Cuchet, 2010).

The orientation of the screen surface plays an important role regarding to its effect on fish behaviour. According to Pavlov (1989) and Larinier (2008) the exposition of a slight angle to the flow direction and a bypass at the downstream end of the screen promote the guiding effect of the barrier (Ebel, 2013). Thereby the angle of the screen surface should be less than 45° (Larinier & Travade, 2002).

Clear width between the bars is a very important parameter in the design of a mechanical barrier. The physical permeability can be described by the dimensionless ratio of clearance of the bars to the height of the body, called permeability index (Ebel, 2013). According to investigations of Pavlov (1989), the maximum protection was observed at ratios < 3. Therefore, the effect of mechanical barriers is not only based on their physical impermeability but also significantly on their impact on fish behaviour. Local turbulences and eddies are generated through the flow between the cables, which affect fish behavior according to a haptic stimulus. Furthermore, the visual effect of the barrier can induce a reaction of fish close to the surface area.

For the determination of the clear width, the body height of the target species and stage of growth have to be consulted. It is expected that slight oscillations of the steel cables induce an effect on fish behaviour in a way that fish will avoid contact with the screen surface. This may lead to an the improvement of the fish protection function, but has to be validated by ethohydraulic tests.

Behavioral barriers make use of the biological factors on the orientation and behavior of fish by a change of light, turbulence, electrical charge and sound stimuli. These types of barriers were mainly implemented to deter fish from entering water intakes; applications on hydro power plants exist but with a high uncertainty regarding their efficiency (DWA, 2005). The fish protection efficiency is strongly influenced by parameters like lighting conditions (e.g. daytime, turbidity), water temperature and particularly the flow conditions expressed by the flow velocity (DWA, 2005; Ebel, 2013).

A hybrid facility which combines the physical and behavioural retention of fish from the turbine intakes might cause an improvement to the protective purpose. Thus natural oscillations of the cables of the flexible fish fence and additional artificial stimuli like light, sound and electrical charge have the potential to deter fish from the intake. Nevertheless, these behavioural effects have to be observed in experiments with fish –if possible – under natural conditions, corresponding to the target river.

1.3 Principle of the flexible fish fence

The flexible fish fence consists of horizontally arranged cables situated across the turbine intakes, which repel fish physically and by behavioural influencing stimuli (visual and hydrodynamic-haptic) from the turbine intakes of a run-of-river plant. During normal operation, the cables are in place and fish protection can be ensured. Local clogging at the surface caused by small branches, leaves or grass cuttings can be mobilized by releasing individual cables or cable clusters. At discharges carrying floating matter the cables are released and hence lying on the river bed. The cables are cleaned during this process and floating matter is transported further downstream. Thus, the risk of driftwood jams in case of a flood event is reduced and the entire cross section is available for discharge. During the released mode, turbines are switched off and there is no risk of fish entrainment. The various modes of operation are illustrated in a very simplified way in Figure 1.

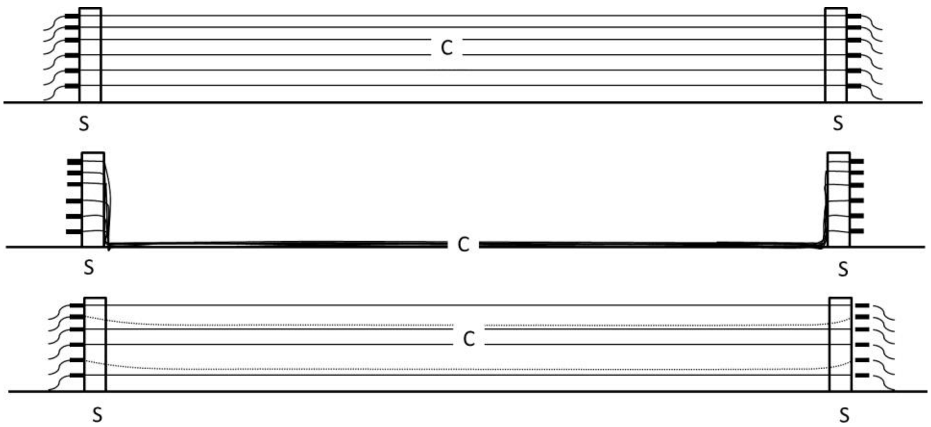

Figure 1 Simplified scheme of the modes of operation (C = cables; S = support): flexible fish fence in operation mode (above), released mode (center) and relaxation of individual cables (below)

The cleaning process works well at overflowed power plants, where floating matter entering the inlet structure can be discharged over the plant and maintains in the ecological system. Furthermore, it is applicable for the ecological upgrading of existing hydro power plants, where a trash rack cleaning system in front of the turbine intakes exists (Böttcher, 2012).

2. Model test

In a first step the flexible fish fence concept was implemented with a length of 18 m at the laboratory of the Unit of Hydraulic Engineering, University of Innsbruck. The aim of this preliminary test was to get a first impression about the basic functionality concerning the shift between the different modes of operation and the behaviour of suspended cables. After the first satisfactory results, further investigations into flow conditions were carried out. For this purpose, the flexible fish fence was installed at a scale of 1:5 in the channel of an existing model test in the laboratory. As shown in Figure 2, the barrier structure was placed in the channel at an angle of 45 ° to the flow direction. Again the main focus in the experiment was to test the basic functions and mechanical behaviour of the cables during the two modes of operation.

Additionally, the scenario of a driftwood jam in case of higher discharges was simulated by an input of leaves and branches across the entire water surface. The behaviour of the cables and the sag of the cables were observed thereby with focus on the need of a constant clear width for fish protection.

Moreover, the cleaning effect in case of a driftwood jam was investigated. Thereby two hydraulic loading conditions (maximum water level; all cables are submerged - maximum velocity; highest dynamic pressure) were observed separately for leaves and wood.

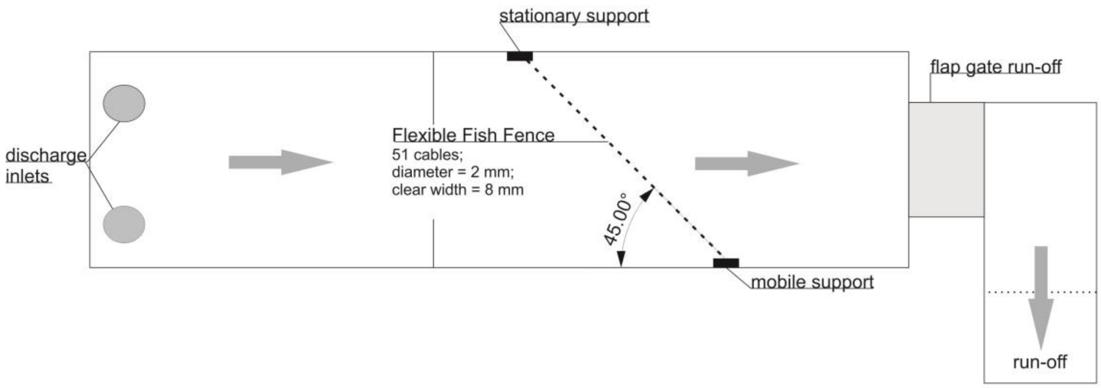

Figure 2 Layout of the model test

Figure 3 and Figure 4 illustrate the results of two tests, where the cleaning function of the flexible fish fence was observed. Within one test, floating matter was carried along the entire cross section upstream of the structure in order to simulate a driftwood jam. After the surface was clogged with the material, the cables were released and floating matter was remobilized. Finally the cables were tensioned again and the results of the cleaning process were analysed. The results demonstrated that the majority of floating matter was remobilized by relaxation and re-tension of the cables (see final states in Figure 3 and Figure 4). Most of the material (particularly leaves) accumulated in the sharp angle and in the region of the water surface. Here it is important to note that with the simplified construction in the model test it was not possible to completely release the cables. This fact causes a higher risk of a driftwood jam, especially in the sharp angle of the facility. In nature, the support structure has to be chosen in such a way, that the cables can be completely laid down to the river bed. Furthermore the floating matter, which was employed for the tests, was not adjusted to the model scale in order to be on the safe side.

Taking the simplifications on the model test into account, the cleaning process works well. Oscillations of the cables were strongly attenuated by the water and thus the magnitude of the oscillations did not exceed the clear width between the cables. Furthermore the frequency of the oscillation increases with higher flow velocities and thus the amplitude declines. This high-frequency oscillation may have a significant effect on fish behaviour; nevertheless reliable statements can only be made if the flexible fish fence is further investigated in an ethohydraulic test (Böttcher, 2012).

Figure 3 Test with leaf input: (1) initial state, (2) relaxation of the cables, (3) transition to operation mode, (4) final state after cleaning

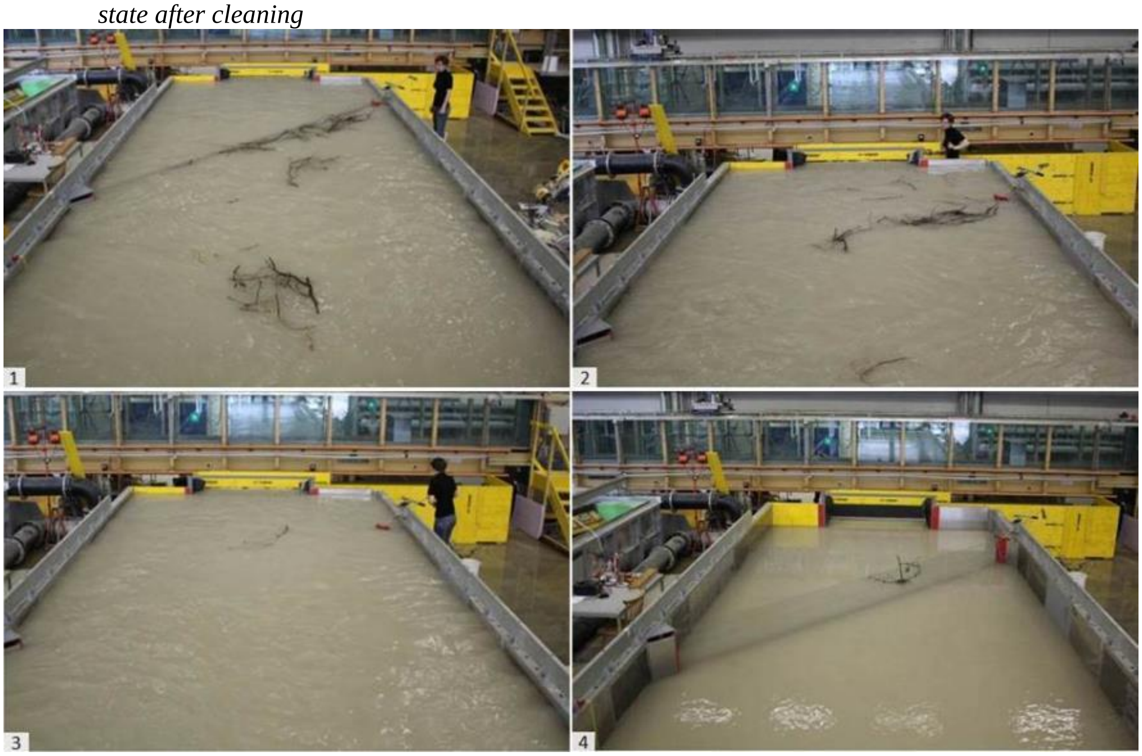

Figure 4 Test with branch input: (1) initial state, (2) relaxation of the cables, (3) transition to operation mode, (4) final state after cleaning

3. Applications

The flexible fish fence was developed as part of the design of “river flow power plants” at the lower Salzach River, in cooperation with the energy provider Grenzkraftwerke GmbH. A “river flow power plant” is overflowed; thereby discharge over the power plant is regulated by weirs. In case of higher discharges the cables of the fish fence are released and floating matter is transported further downstream. In addition, a coarse screen in front of the turbine intakes is necessary for the protection of machine parts. Under detailed consideration of the site parameters (amount of floating wood, etc.) a thrash rack cleaning system for the coarse screen is not needed. Nevertheless this has to be decided individually for every case. The layout of the flexible fish fence, implemented in the draft of the hydro power project at the lower Salzach River is shown in Figure 5. The flexible fish fence is located at the bed load barrier upstream of the power plant intake. The fence is 80 m long and situated between the river bank and the middle pier. Its inclination is 30° to the main flow direction. About 100 steel cables are planned to be installed over a height of 4.0 m. A bypass for fish downstream migration is located at the downstream end of the fence.

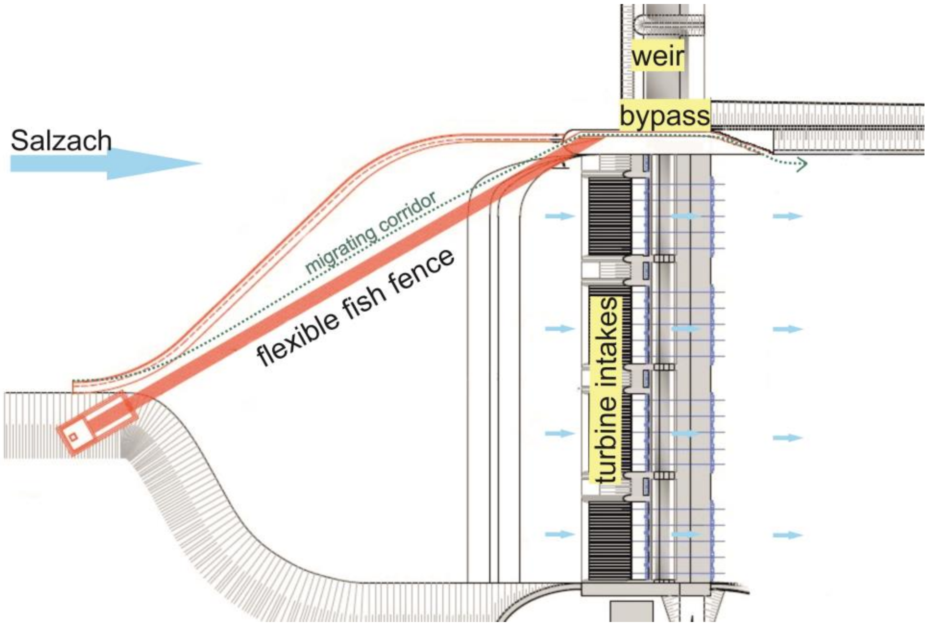

Figure 5 Layout of the flexible fish fence at the river flow power plant; downstream migrating corridor for fish is shown dashed

Many other options for the application at other types of run-of-river power plants exist. Some examples are sketched in Figure 6. The position of the flexible fish fence can be easily modified according to the requirements regarding geometry or fish protection purposes. This offers a high potential for the ecological upgrading of large scale hydro power plants due to a high degree of adaption to existing structures.

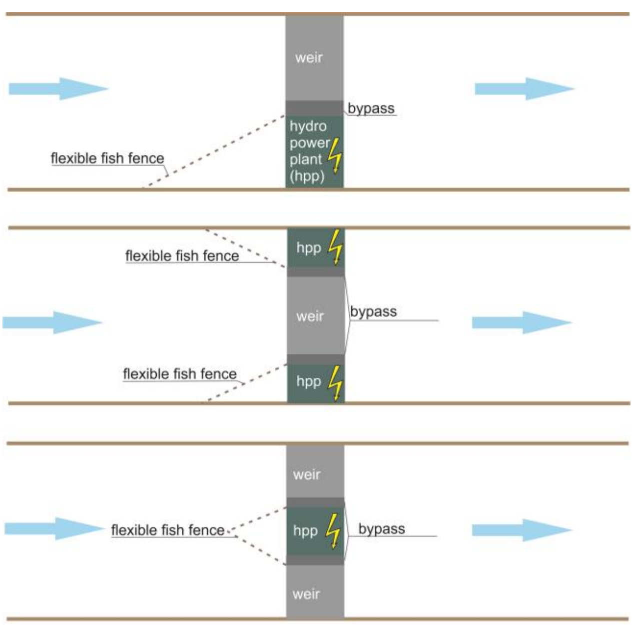

Figure 6 Layout of the flexible fish fence on different types of run-of-river plants

4. Technical feasibility

In cooperation with steel and cable construction companies several supporting and pre-stressing mechanisms were designed and evaluated. The fish fence for the hydro power project at the lower Salzach River has a length of 80 m and a height of 4.0 m (see Figure 5). With a clear width of 30 mm about 100 cables have to be installed. The following technical requirements must be observed in the design and dimensioning of the technical concept of the flexible fish fence: The cables have to be controllable separately or in small clusters in order to flush local cloggings and guarantee a constant pre-stress. The relaxation has to take place in a uniform way in order to prevent the cables from getting caught. Furthermore, pressure sensors for detecting the degree of clogging and sensors for detecting the position of cables and pre-stressing forces have to be integrated into the automated control system of the hydroelectric power plant. Considering these constraints a pre-stressing technology using a hydraulic system was developed in cooperation with the company Albatros Engineering GmbH. Every cable is controlled via hydraulic cylinders, which can be operated separately and in clusters . The principle is illustrated in Figure 7 and highly simplified. All cables are operated electrohydraulically by a hydraulic power unit.

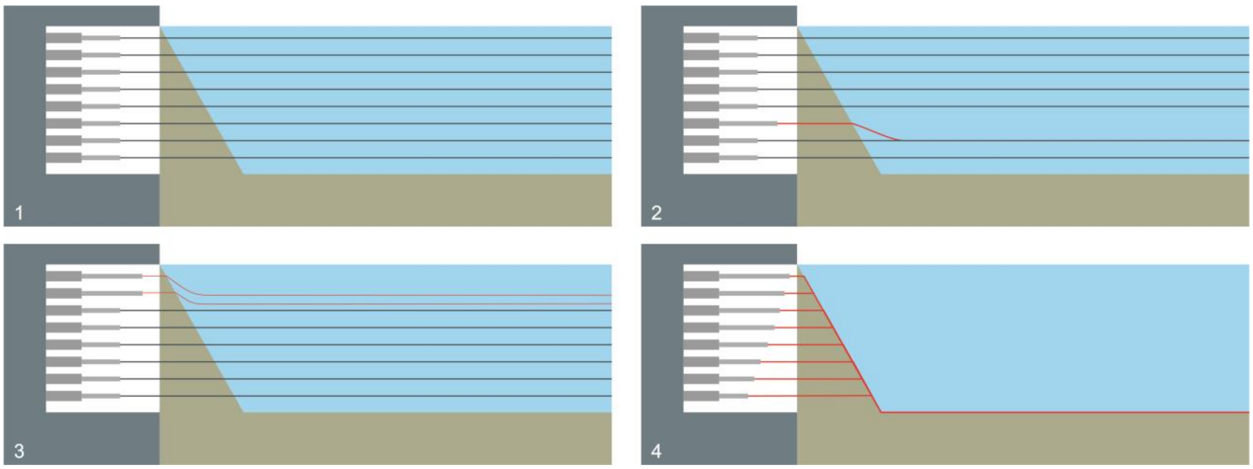

Figure 7 Principle of the hydraulic system: state of operation (1), relaxation of an individual cable (2), relaxation of a cable cluster (3), released mode (4)

5. Conclusion and prospects

The flexible fish fence is an innovative fish protection system, which was developed at the Unit of Hydraulic Engineering, University of Innsbruck, Austria. It consists of horizontally situated steel cables, which are located upstream of turbine intakes.

The horizontal arrangement of the cables is beneficial regarding fish protection and fish behaviour. Due to the inclined position fish are guided towards the bypass at the downstream end of the fence.

Model tests demonstrated the basic functionality of the flexible fish fence during different modes of operation. It was shown that the clear widths between the submerged cables of the flexible fish fence remain constant and a cleaning effect can be achieved. Oscillations of the cables due to flow conditions may have an additional deterrent effect on fish, as well as a combination with artificial transmitted stimuli such as light, sound waves or electrical charge.

The fish protection efficiency and guiding efficiency has to be further investigated by an ethohydraulical study. Thereby the behavioral effect of the barrier itself and additional stimuli will be analysed. By implementing a prototype at an existing hydro power site, the technique as well as further ethohydraulical details will be investigated.

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