

# Research development in measures for downstream migration of fish through dams

Z N Zhai<sup>1,2</sup> and Y Wang<sup>1</sup>

<sup>1</sup>College of Hydraulic and Environmental Engineering, China Three Gorges University, Yi Chang, China

E-mail: 501945196@qq.com

**Abstract.** In order to achieve the purpose of migratory fish through water conservancy facilities safely and efficiently, the development of the research on the measures for downstream migration of fish through dams at home and abroad is provided to prove which measure is more effective for fish through dams. In this paper, Surface Bypass Collection (SBC), using the characteristic of fish to find suitable water flow, is introduced in detail. At the same time, “Fish-friendly” turbine, using the flow passage as the way for fish to pass through the dam, is put forward as a new idea. The feasibility of the design and the cases of the practical engineering are also described. Because of the differences of fish species and water environmental factors between civil and abroad, successful projects abroad can’t be copied directly. In view of the deficiency of the design and demonstration of “Fish-friendly” turbine, some suggestions are put forward for the selection of the measures for fish pass through the dam and the existing problems of applicable conditions.

## 1. Introduction

Since the construction of large water conservancy projects, the contradiction between the protection of natural ecological environment and the development of hydropower has become one of the main problems that puzzled the experts and scholars. The dam not only blocks the routes of migration fish, but also breaks the complete water ecosystem into discontinuous environmental units, destroys the whole life history of fish, cuts off the gene exchange between populations. Therefore, the development of the traditional fishery industry and the protection of the ecological diversity of rare fish species are affected. With the vigorous development of hydropower, the contradiction is becoming more and more acute, and whether the hydropower project is friendly to the environment has become an important index to evaluate completed projects and projects under construction. Among them, the ability of fish pass through the dam is the key part of this evaluation system [1].

In order to help fish to complete their whole life history, it is the same important to study measures for fish through the dam upstream and downstream. At home and abroad, the research on the measures of fish pass through the dam upstream is far earlier than that of fish pass through the dam downstream, and the research results are also significant [2]. However, the research and practice of the downstream facilities are not as good as the upstream facilities [3]. This article will focus on the problem of passing the dam downstream, analysis results in different periods at home and abroad, and discusses the characteristics and practical scope of various techniques to help fish to cross dam downstream. Then, some suggestions and thinking will be put forward to improve the survival rate of fish.



## 2. Study on the technology of fish passing dam downstream

According to the different ways to help the fish to pass through the dam, measures can be divided into three types: by overflow, by transportation, and by the flow passage of turbine [4].

By overflow, just as its name implies, the measure uses the behavior of migratory fish activity in the surface of the water layer to find the appropriate flow rate, and uses the water discharge from fish passage facilities or spillway to help the fish over the dam seems as “soft landing”.

As for transportation, through the blocking fish, luring fish means, for example, light induction [5], the bubble wall [6], fish corral and so on [7], we gather the fish at the designated location, and help them pass through the dam downstream by fishing boat and fish lift.

Passing through the dam by the flow passage of turbine needn't the aid of any auxiliary facilities. The fish is attracted by the natural flow rate of the water inlet of the power station, and come out from the draft tube into the downstream of the river.

By overflow is usually regarded as one of the most secure methods of juvenile fish, and the mortality rate is only 1%~2%. However, in order to achieve the safety of passing the dam downstream, we need to accurately design overflow installations, and downstream water cushion area can reach deep enough. Because the discharge water inevitably draws gas in the air, it is inevitable that the downstream water will produce “Supersaturated nitrogen” [4]. If the saturated gas attach upon the respiratory tissue of fish, the fish will lose equilibrium resulting in injury or even death. What's more, the discharged water will cause the economic loss of hydropower station.

When we take the measure of transportation, it is necessary to set up fishing net at the upstream inlet of the power station [4]. From the engineering point of view, this setting will not only seriously affect the efficiency of the hydraulic turbine, but also cause the damage to the turbine because of the fishing net debris passing flow passage by error. However, it is necessary for the barring fish establishment to do some preventive maintenance and servicing at regular intervals. At the same time, fish is a vulnerable group living in the water, especially the juvenile fish will be injured or even dead because of the huge suction flow rate at the entrance of the power plant into the net. Adult fish will also be due to repeatedly collide the fishing net in a long time resulting in fatigue, and predatory fish and birds can prey on them easily [4].

Although there are many advantages for fish passing through dam by flow passage of turbine, such as simple operation, full depth of water cover and minimum artificial auxiliary facilities, the complexity of the flow path of hydraulic turbine and the coupling of many hydraulic factors can cause the damage of the fish. For example, Heisey *et al* [6] measured the fish damage rate reached about 12% in casualty test for adult American shad (length more than 35 cm) passing the turbine in Kaplan area.

### 2.1. Foreign study on the technology of fish passing dam downstream

**2.1.1. Fish pass through dam by the flow passage of turbine.** In traditional view, it is believed that the complex flow environment of the turbine will inevitably cause great damage to the fish. In 1995, the U.S. Army Corps of Engineers (USACE) set up a turbine runner fish survival study group. The team divided the injury mechanism of fish passing through the turbine into 4 categories [8]: mechanical damage, pressure gradient damage, turbulent shear stress damage, and cavitation damage. Mechanical damage includes abrasion, grinding and strike, but the changes of pressure gradient, cavitation, turbulent shear stress are all the performance of hydraulic characteristics. Through the analysis of the experimental phenomena and experimental data, USACE made two main direction of fish-friendly turbine design: One is optimizing the overall structure of the hydraulic turbine to reduce the probability of mechanical damage to fish, the other is improving the performance of turbine runner in order to reduce the influence of hydrodynamic factors on the health of fish.

As early as the beginning of 1990s, The United States Department of Energy (DOE) has launched a research program aimed at improving the survival rate of fish passing through the turbine called Advanced Hydropower Turbine System Program (AHTS) [8]. There are two hydraulic turbine

development and design companies won the bidding to participate in “Fish-Friendly” turbine design and development. One came from a team of engineers and biologists at Alden Research Laboratory, Inc. (ARL) and Northern Research and Engineering Corporation (NREC), and mainly focuses on the design of new hydraulic turbine runner to reduce the damage to the fish. Another proposal came from a team led by Voith Hydro, Inc. (called Voith team) to improve existing runner designs [8].

The ARL team made a new design of hydraulic turbine runner blade structure [9] and draw a spiral line shape blade (figure 1) basing on injury mechanism research of traditional turbine runner flow passage [10], which can guarantee the working efficiency of turbine (about 90%) and excellent cavitation performance at the same time, but also to ensure that the safety area of fish passing turbine. The diameter of the new runner is 1.5~2 times of the traditional turbine, so it is only suitable for the new hydropower station [11]. It is more difficult and expensive to replace the new hydraulic turbine runner with large size for the existing power station with limited size [12]. For example, a power station in the United States Columbia River Basin has carried on the economic evaluation of the ARL turbine in 2010, The results show that the turbine runner flow passage and the plant expansion cost of the ARL turbine installed 13.6 MW is about 2,340,000 \$, which is higher than that of the traditional turbine installation cost of about 210,000 \$ [13].



**Figure 1.** Schematic diagram of ARL turbine runner.

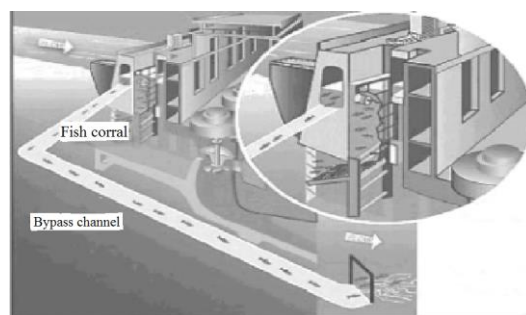


**Figure 2.** Schematic diagram of MCR.

The Voith team regarded optimizing the turbine flow passage structure and hydraulic conditions as the goal to optimize the structure of traditional turbine. Such as, optimization of fixed guide vanes, reducing the height of the guide vane, polishing weld, less number of blades, thicker blade inlet edge to ensure the flow passage and pressure transition smooth. The probability of mechanical damage to the fish was reduced by using the minimum clearance runner (MCR figure 2) [14]. In 2005, the MCR was used in Wanapum hydropower station in Grant County public facilities management area, Washington, and the results showed that the damage probability of fish was reduced effectively [15,16].

**2.1.2. Surface bypass collection facilities.** According to the feature that most of the juvenile migratory fish in Columbia basin enjoy finding surface water (3.05~6.10 m), Wells hydropower station staff through field experiment shows that manufacturing flow to attract juvenile, with relatively small amounts of water assisting a large number of juvenile through dam has become possible [17].

It was found that juvenile migratory fish distributed in water within the range of 21.33 m along the vertical direction in Lower Granite hydropower station in Snake River Basin. By installing the barring fish establishment in the top surface of the water inlet of the water turbine, we can prevent the fish from the turbine inlet and guide the fish into the gallery in front of the dam, then, assist the migratory fish through dam downstream safely by surface bypass collection facilities (figure 3) [17].



**Figure 3.** Surface bypass collection facilities.

Through long-term observation and monitoring, this kind of measure for migratory fish passing the dam was basically feasible; however the barring fish corral also caused some damage to the juvenile, especially for smaller fish. The data from Bonneville second power plant surface bypass collection system in the Columbia river basin showed that: the system to the juvenile fish (age 0~1) direct and indirect damage rate was up to 20% [17].

In foreign countries, fishway in hydropower station set has become a mandatory requirement, thanks to the fishway (upstream fish facility) construction experience, downstream facilities for fish survival rate is increased accordingly. For example, the fish survival rate of the famous Bonneville dam downstream fishway has increased from 91.7% in 1999 to 95.9% in 2005 [17].

## 2.2. Study on the technology of fish passing dam downstream in China

In our country, there is no unified and effective solution for migratory fish passing through dam downstream because of less research; therefore, the realization of fish through dam mainly depends on the surface of spillway and flow passage of turbine, even passing dam by fishway (upstream facility) directly. However, according to the runtime detection data of vertical perps type fishway (Capacity design of fish: The number of upstream is 7000 tail/day, downstream is 50000 tail/day) in Laolongkou hydro-junction in Hunchun river, Jilin province, there are 5 to 8 species of fish through the fishway upstream, but for *Oncorhynchus masou*, *Oncorhynchus keta*, the effect is unsatisfactory [18].

Fishway construction in China started late, and the fish downstream dam technology is still at the stage of theoretical and experimental research. There are no outstanding examples of typical engineering for reference.

## 3. Thinking and prospects

Nowadays, the development of fishing passing dam technology mainly revolves around the optimization of flow passage structure of turbine and research on surface bypass collection facilities, but the two methods also faced some problems.

- The construction of surface bypass collection facilities cannot do without the application of mature technology (such as sound, light guide fish, bubble wall, etc.) of auxiliary collecting fish, and this technology is still in the experimental stage of development. Vowles *et al* [19] used a specific intensity light source to realize the directional driving *Salmo trutta* through dam downstream, but the effect is not obvious on other species. To avoid the fish into the turbine by error, we need to set up the barring fish nets in the top surface water of power station inlet. At the same time, regular replacement and maintenance for barring fish nets is a huge cost. The working efficiency of the turbine will be affected and the runner blade will be damaged because of the relic of barring fish nets by big fish impact. Small fish at the entrance of the power station will be injury and death, when they sunk into the nets because of the attracted flow. But for the fish living in surface water, this facility played a very significant role.
- Turbine passage technology relies on analysis method of combining numerical simulation and

simulation experiment to achieve optimal design of the flow passage of turbine, while avoiding setting the barring fish nets, reducing auxiliary engineering investment, but it is not a small sum of investment for the replacement and installation because of the existing power station size constraint. At the same time, the cognition and development of the "Fish-friendly" turbine is still in the exploratory stage [10,16], the realization of this technology depends on not only the traditional hydraulic structure, but also the cross application of fish behavior and water ecology. The proposed design not only integrates the contradiction between the traditional fish facilities and the hydraulic power system, but also realizes the adjustment of the water conservancy project to the natural ecology; the proposed design not only plays out the advantages of hydraulic turbines, but also makes the arrangement of fish passing dam facilities more flexible. However, the complex hydrodynamic characteristics and flow passage structure of the turbine are the key factors affecting the efficiency of the turbine.

- The biological criteria for the hydraulic characteristics damage of fish have not been established. The foreign experimental team, Cada [20] has launched a targeted experimental study with the support of DOE and AHTS. Domestic fish is different from foreign countries, especially for rare and protected fish and fish with research value. For example, foreign salmon and trout parent fish will not face the problem of passing dam downstream after they spawning, but fish in our country belong to multiple spawning. How to create a safe and appropriate hydraulic characteristics for adult and juvenile fish to ensure the safety of fish passing the dam, only based on the biology of uniform standards, scientific experiments are justified, many experimental results can achieve the transformation of scientific research.
- Aiming at the problem of structure optimization of turbine runner, we can study the suitability and the relevant threshold method of main migratory fish passing hydraulic turbine to ensure main hydraulic factors (such as pressure gradient, flow velocity, turbulent kinetic energy), and clear optimization goal and biological standard turbine hydraulic factors, in order to improve the turbine efficiency of fish [21].
- In order to reduce the mortality rate and damage rate of fish passing through the dam, it is necessary to establish the mechanism of quantitative evaluation of the advantages and disadvantages of fish passing through the dam.
- The weighting matrix method can be used in the evaluation of the measure for fish passing through the dam downstream. According to the weight ratio of different hydraulic factors, we can get the final score after the reasonable operation. Then, we can design the assembly algorithm based on the thought. The main parameters of different hydraulic turbines are calculated as the initial conditions of the computation program, and the corresponding scores can be obtained by calculation, then, we divided the final score into "Fish-friendly" rank. For example, the output results (less than 60) are not up to standard, 61~90 points is general effect of fish passing dam, 91~100 points is the excellent effect of fish passing dam (percentile system). Thus, a scientific and effective post evaluation mechanism is established.

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