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Review of the Current Status of Vertical Slot Fishway Design

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Abstract: As a main layout method of engineering fishways, the vertical slot fishway is characterized by high efficiency and wide application. By referring to relevant data, this paper briefly introduces the basic situation of the vertical slot fishway, describes its design development process at home and abroad, and provides suggestions for the current deficiencies in the research of fishways.
Keywords: Fishway; model test; numerical simulation; hydraulic engineering issue.

I. INTRODUCTION

The construction of water conservancy facilities such as dams, embankments, and sluice gates on river channels is an important water conservancy project. These facilities have brought huge economic benefits to human society. However, among them, the construction of dams and embankments will make the river channel "half-cut", showing a discontinuous characteristic, breaking the original ecological continuity rule, and triggering a series of ecological crises. In order to compensate for the impact of water conservancy and hydropower projects on the ecological environment, we often build fishways according to the unique ecological environment of the river[1]. Therefore, a reasonable fish passage facility is an important way to restore the vertical connectivity of the river channel. According to the current status of fish passage facilities, improving the design of fish passage facilities and improving the efficiency of their use is of great significance for the restoration of healthy fish populations.

The world's first fishway was built in the 17th century. By the 20th century, with the rapid economic development of Western countries, people's demands for hydropower energy, flood control, irrigation, urban water supply, and other aspects were getting higher and higher. At the same time, the impact of these projects on fish resources was becoming more and more prominent. Nowadays, many dams and embankments have been built in countries around the world, but there are many successful and failed cases among them[2]. Therefore, a suitable fishway design plays a significant role in the establishment of a river ecosystem.

The vertical slot fishway is an efficient and widely used fish passage engineering facility due to its good incoming flow conditions, defined backflow area, and strong adaptability to the water levels of the upstream and downstream[3]. The fish passage channel of the vertical slot fishway is a vertical gap, which is divided into the general vertical slot type and the guided vertical type according to whether there is a guide plate for isolation. The guided vertical type is further divided into the same side, the opposite side, and the bilateral type. Among the existing fishways, the vertical slot type is a more efficient and easy-to-build fishway. Its advantage is that it allows fish to swim in the water depth they prefer and swim upstream along the fishway; when the water levels of the upstream and downstream change, the vertical slot fishway still has a certain stability and allows fish to pass through; compared with the perforated or grooved fishway, the fishway is not easy to be blocked; in addition, the vertical slot fishway also has the advantages of strong energy dissipation ability, simple structure, and easy maintenance[4].

II. DEVELOPMENT STATUS OF VERTICAL SLOT FISHWAY DESIGN ABROAD

In 1662, the province of Béarn in France passed a law requiring the construction of a road on a dam for fish to pass through the dam. However, before the 20th century, there were no scientific-based experiments and explorations. In 1990, Denil published a paper introducing a new type of fishway independently developed by him, which was based on scientific theory. This new type of fishway was called the Daniel fishway and was widely used[1]. The Bonneville Dam on the Columbia River built a fish passage facility in 1937-1938 and introduced a variety of fish collection equipment. From 1939 to 1940, McClelland and Nemeny studied the relationship between the fishway and fish behavior. Since then, the issue of fishways has received increasing attention, and more and more basic research has been conducted on the efficiency of fishway passage and other aspects[1]. According to incomplete statistics, by the early 1960s of the last century, there were more than 200 fish passage facilities in Canada and the United States, and more than 100 fish passage facilities in Western European countries, mainly fishways. By the end of the 20th century, the number of fishways in the world had increased significantly[5].

At present, there have been many studies on the hydraulic performance and design methods of vertical slot fish passage facilities, and many research results have been achieved. Rajaratnam et al. believe that the width-to-height ratio of each pool in the fishway is around 10:8, which can achieve better fish passage effects[6]. Larinier et al. believe that the energy dissipation rate per unit volume in each pool should not exceed 150-200 W/m3[7]. The attraction rate of vertical slot fishways to fish is 0-100%, with an average of 63% and a median of 80%[8]. In 1943, Canada built a fish passage called "Hell's Gate Fishway" on the Fraser River, which was the world's first vertical slot fishway. The two sides of the water tank of this building need to be installed with partitions, so that the water flow can enter the pool room through the two vertical slots between the partitions. The vertical slot fishway mainly uses contraction, diffusion, and backflow as the main energy dissipation methods, and is suitable for fish with small differences in swimming speed. In 1994, Australia reconstructed some of the original weir-type fishways into vertical slot fishways, and the amount of fish passing through and the types of fish passing through have been significantly improved[9].

III.4 DEVELOPMENT STATUS OF VERTICAL SLOT FISHWAY DESIGN IN CHINA

Compared with foreign countries, the research on fishways in China started in the 1960s. The development of fishway research in China can be divided into three stages: the initial stage (1960s-1970s), the stagnation stage (1980s-1990s), and the second development stage (after 2000)[10]. Compared with foreign countries, the research on fishways in China is not deep enough. Although the earliest research on fishways in China began in the 1950s[2], many fishway projects were built unsuccessfully. The Doulonggang Fishway in Dafeng County, Jiangsu Province, the Yuxizha Fishway in Anhui Province, the Liuhe Fishway in Jiangsu Province, and the Yangtang Fishway in Hunan Province all had problems such as "no fish in the water, siltation in the fishway, and low utilization rate of the fishway". Therefore, since the 1970s, many water conservancy projects have abandoned the fishway, resulting in a decades-long gap in the development of fish farming technology[11]. The main reason for the stagnation stage is the controversy over the fish passage engineering measures of the Gezhouba Water Control Project[10]. In the end, the Gezhouba adopted the method of a breeding and releasing station to protect rare species such as the Chinese sturgeon, but existing studies have shown that the downstream of the three gates of the Gezhouba Dam is the area where the Chinese sturgeon population gathers most densely, implying that fish still need to swim upstream along the dam[12], which means that simply establishing a releasing station cannot fundamentally solve this problem, but only fundamentally solve the problem of the migration of the Chinese sturgeon, let alone maintain the circulation of the river and the ecological environment.

In the second development stage, people's awareness of environmental protection has improved. Many water conservancy facilities with conditions are required to add fishway engineering facilities to protect the diversity of fish species and reduce the impact of humans. Such as the Shangzhuang Sluice in Beijing[13], the Changzhou Water Control Project in Guangxi, and the Cao'e River Tide-blocking Sluice in Zhejiang.

There are mainly three types of fishways used in water conservancy projects: the Daniel fishway, the pool-weir fishway, and the vertical slot fishway. The vertical slot fishway has the widest application range in China. According to statistics by Jin Zhijun et al.[8], from 1958 to 2018, 59.2% of the built fishways in China were vertical slot fishways.

In recent years, many Chinese scholars have made contributions to the design research of vertical slot fishways and solved many existing problems. Xu Tibing et al.[14] believe that in the vertical slot fishway, the length-to-width ratio L/B of the pool has a greater impact on its flow characteristics. From the perspective of saving engineering investment, the length-to-width-to-height ratio of 10:8 is appropriate. And whether to set up piers in the partition, its impact on the flow structure is limited. From the perspective of preventing the retention of floating objects and the prevention of sediment deposition, in the actual fish passage facility, isolation piers can be omitted.

Zhang Guoqiang et al.[7] conducted in-depth research on the influence of these data on the flow structure by selecting different parameters such as the length-to-width ratio of the vertical slot fishway, the length of the guide plate, and the guide angle, and using numerical simulation methods. They believe that when the vertical slot width b/B of the vertical slot fishway is 0.15 to 0.20, the velocity trajectory line basically located in the center of the pool will be obtained, and the effect of good energy dissipation along the mainstream area and a more uniform radial velocity and stable transverse velocity will be obtained.

Rong Guiwen et al.[15] simulated and calculated the hydraulic characteristics in the fishway through the RNGk-ε turbulence model and the VOF method, and concluded that the relative position change of the vertical slot has a greater influence on the mainstream of the water flow. With the increase of P/H, the curvature of the mainstream increases. When $P/B \geq 0.42$, the phenomenon of mainstream wall attachment will occur, and the area of the left backflow area is too large, which is not conducive to the migration of fish; in the range of P/B value of 0.26-0.34, the flow pattern distribution in the pool room is better;

Lyu Yangyang et al.[16] based on the RNGκ-ε turbulence model, comprehensively considering factors such as the angle of the diversion plate at the head of the pier and the relative position of the diversion plate, constructed the flow field of the vertical slot fishway pool in 12 different working states, and analyzed the influence of pier structure, horizontal spacing of the guide partition, and other factors on the internal hydraulic performance of the vertical slot fishway pool. They believe that the maximum value of the mainstream velocity in the vertical slot fishway appears at the tip of the guide plate, and when the relative position of the guide partition is about b0/L = 0.15, a better velocity flow pattern can be obtained, which is conducive to the migration of fish.

Wang Meng et al.[17] aimed at the phenomenon that vortices are easily generated in the cracks of the vertical slot fishway, which makes the water flow in the fishway disordered. Taking the pool room in the vertical slot fishway as the research object and the Reynolds stress (RSM) model as the research method, they established the same-side vertical slot fishway with different structural forms and conducted numerical simulation research on it. They believe that when an obstacle is arranged at a distance b0 downstream from the vertical slot, the maximum velocity in the vertical slot hardly changes, but the velocity gradient between the vertical slot and the obstacle will decrease. When arranging square and semi-cylindrical obstacles, due to the influence of the edges, the turbulent kinetic energy increases; the Reynolds shear force slightly decreases at the vertical slot of the pool room, while it increases behind the obstacle. When arranging a cylindrical obstacle, the Reynolds shear and turbulent kinetic energy in the vertical slot can be reduced by 20%-30%, which can significantly improve the hydraulic characteristics of the fishway and meet the upstream needs of more fish.

Yan Xiaoming et al.[18] aimed at the problem that the vertical slot fishway commonly has construction and assembly errors in practical applications, in order to clarify its impact on the hydraulic structure of the pool room, they constructed 7 calculation conditions with different inclinations of the guide and partition (α within ±15°) by using three-dimensional data simulation as the main method. They found that when the inclination angle α is within the range of ±15°, the standard deviation of the vertical velocity distribution is about 0.12, which indicates that the binary flow structure at different water depths has a certain similarity; when the inclination angle α is within the range of ±15°, the positive and negative of its angle have little difference in the affected area, and the change of the inclination angle causes the distribution range of the mainstream trajectory line to change, especially when it is -5°, the amplitude of the main trajectory line increases by 120%; with the increase of the inclination angle, the increment of turbulent kinetic energy and total hydraulic strain both show an increasing trend. When α is within the range of ±15°, the impact on the hydraulic characteristics of the fishway is much greater than when α is within the range of ±10°, especially when α is within the range of ±15°, the distribution increase of the turbulent energy and the total hydraulic strain of the water flow is 152.7% and 368.2%, respectively.

Yang Chao et al.[19] in order to solve the problem of poor water flow conditions and unfavorable for fish to migrate upstream at the 180° turning point of the vertical slot fishway, proposed measures such as increasing the length of the front and rear sections of the turning section and adding guide plates. Based on the unique TurVOF technology of FLOW-3D, they conducted data simulation calculations on the water flow pattern, velocity, turbulent kinetic energy, and turbulent dissipation rate of four different turning section cross-sections. They found that when the length of the front and rear sections of the turning section is appropriately extended, it is beneficial to the improvement of the water flow pattern and the migration of fish. When the length of the front and rear sections of the turning section is extended and the guide plate is added, the turbulent kinetic energy and turbulent dissipation rate at the upstream of the turning section and the vertical slot will increase, but this has little impact on the migration of fish.

Li Su et al.[20] used the RNGk-ε model in Fluent as a tool to conduct experiments on the water flow pattern, velocity, and kinetic energy distribution in the pool of three improved schemes, and determined the optimal scheme. They believe that only removing the guide plate can reduce the average velocity in the end vertical slot, but it will make the mainstream in the pool too dense and the area of the backflow area larger, which is not conducive to the dissipation of water flow kinetic energy. Removing the outlet guide plate at the end of the pool and adding a partition downstream can significantly increase the dissipation of water flow kinetic energy at the drainage outlet and make the average flow velocity of the end vertical slot have a greater decrease.

IV. CONCLUSION

Compared with the research on fishways abroad, China started relatively late and still has some problems at present. We should have a correct understanding of the construction of fishways. In foreign countries, the construction of fishways was originally to protect native precious fish[10], and the construction of fishways can not only protect biodiversity, but also facilitate the longitudinal connectivity of the river. The correct use of fishways not only conforms to the concept of green development but also is an important measure to compensate for the negative impact of dam blocking.

At the legal level, China's legal regulations and construction norms for fishway construction are relatively lacking, which seriously restricts the development of the design direction related to fishways. At present, the only existing legal regulations are the "Outline of the Action Plan for the Conservation of Aquatic Biological Resources in China" issued by the State Council and the "Technical Guidelines for Environmental Impact Assessment of River Ecological Water Use, Low Temperature Water and Fish Passage Facilities in Hydropower and Water Conservancy Construction Projects (Trial)" issued by the State Environmental Protection Administration[21]. Now, it is necessary to accelerate the improvement of technical standards. At present, it is necessary to urgently compile relevant technical standards to better provide a scientific basis for the design criteria and technical specifications of fish passage facilities for fishway design. At the same time, there should also be corresponding standards for the operation and management after the completion of fishway construction to promote the normal maintenance and operation of the fishway. On this basis, considering the national environmental protection plan, the construction of fishways, fish ladders, and other dam-crossing facilities should be included in the development and construction plan of water conservancy and hydropower projects, and together with the navigation regulations, become a mandatory industry standard.

The design of fishways is not an isolated activity; it is a comprehensive project that integrates multiple disciplines such as water conservancy engineering, ecology, fishery science, and environmental protection. This field requires engineers to not only have solid professional knowledge of water conservancy and hydropower but also must master rich knowledge related to fish ecosystems and fishery management. When planning and designing fishways, we should recognize that this is a complex and systematic project that cannot be completed by a single discipline independently, but requires the joint collaboration, mutual understanding, and support of professionals from different fields.

In order to promote cross-border cooperation and improve the scientificity and effectiveness of fishway design, we should build an open, interdisciplinary cooperation platform. Such a platform can build a bridge for communication between various specialties, ensuring the flow of information and the sharing of technology. In this way, the wisdom and experience of all aspects can be gathered to jointly promote the construction and research of fishways. For example, the environmental protection department can provide suggestions on the protection of the ecological environment of the water body, while the fishery department can provide guidance on the migration and habitat needs of fish. In addition, experts in water conservancy and hydropower engineering can optimize the layout and structural design of the fish passage from a technical perspective.

Therefore, in the process of fishway design and research, professionals from different academic institutions, government departments, and industries should be encouraged to participate. Their perspectives and experience are crucial for the success of the fishway project. Only when these professionals can gather together and communicate fully with an open mind can the goal of fishway design be truly achieved - to meet the basic needs of fish survival while taking into account the sustainable use of the river ecosystem by humans.

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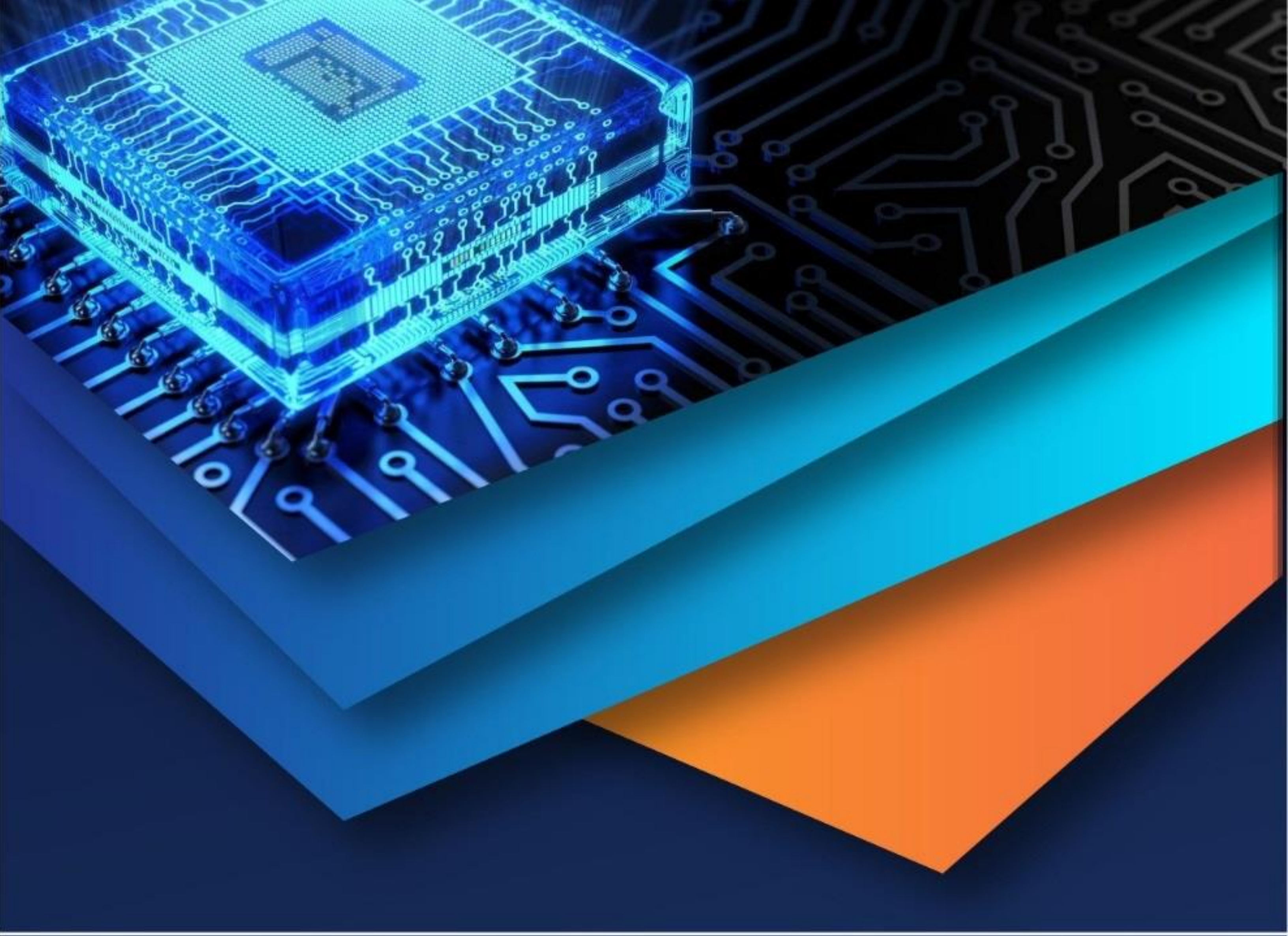

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