A Two-Dimensional Hydrodynamic Numerical Model Applied on Layout of Fishway Entrance and Its Optimizations

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Abstract: The layout of fishway entrance has an important impact on the fish pass activity. In this paper, two kinds of arrangement forms are proposed by analyzing the fish pass objects and the time, the fishway type and the hub dispatching mode for Dayuandu Navigation & Hydropower Complex in Xiangjiang River. Based on the SMS-RMA2 model, a two-dimensional hydrodynamic numerical model with depth-averaged equations is established. The flow conditions at the inlet of different flow rates are calculated and the layouts of fishway entrance are compared and discussed. Meanwhile, the fish pass capacity of different cases is also discussed. The results show that the flow rate at the inlet for case 1 cannot usually meet the optimum flow rate requirement of 0.2m/s ~ 1.3m/s. However, the better results are found in case 2, the inlet flow velocity of this scheme can meet the requirements of the best fish flow rate under various working conditions, except the practical significance of the entrance cannot be showed. Subsequently, two optimization measures are given in this study to avoid the fish cannot find the entrance of fishway, which also provide some reference for similar projects especially the construction of fishway.

1. Background
The entrance arrangement of fishway belongs to the category of fishes behavioristics and hydraulics, and the layout types directly affect the fish pass effect [1]. In the design of the fishway, the entrance arrangement is not only an important content, but also the key to the success of fishway. In order to ensure the effect of additional construction of the fishway project, it is necessary to analyze the position of the entrance of the fishway with the operating conditions and the terrain conditions of the hub, and select the reasonable and feasible entrance arrangement; At the same time, take the combination of migratory fishes and seasonal characteristics into consideration to choose appropriate measures to guide fish and optimize it. At present, The researches on the layout of fishway inlet and the optimization of fishway are as follows: CAO et al [2] outlined the development of fish pass facilities abroad, and summarized the research status about it at home, and introduced the types of fishery facilities at home and abroad; Hohai University and the Nanjing Hydraulic Reserch Institute studied the advantages and disadvantages of entrance arrangement, and the effect of fish pass in the fishway. Videler and Wardle [3] studied the effect of the fishway flow rate on the fish found the entrance; Chen et al [4] designed and researched the Yarlung Zangbo Jiangmu hydropower station fishway engineering through the physical test; Shi et al [5], through the physical model test, combined the Nanxi River water supply project fishway import and tailrace of hydropower station to design the layout. In this paper, the characteristics of the fish habitat and the migration pattern of the riverbank are introduced, and the fishway type is chosen, and a reasonable arrangement for the entrance of the
fishway is made, and the optimization of fishway imports in order to improve the efficiency of fishy fish is explored.

Xiangjiang River is a tributary of the Yangtze River system. The length of Xiangjiang River is 969km and basin area is 94660km². It flows into the Dongting Lake at the estuary of Xiangyin, then flows into the Yangtze River through the East Dongting Lake to Chenglingji. Xiangjiang River is planned to divide into 9 cascade hydropower development.

The Dayuandu Navigation and Hydropower Complex is located in Hengshan County which is about 62km away from the downstream of Hengyang City, built in December 1995, putting into operation in 1998. It is the first complex that built at the middle and lower reaches of the Xiangjiang River Navigation. The control area of the basin is 5.32 million km², a 44.1 billion m³ average annual runoff and the average annual flow is 1400m³/s, equipping with a 1000t ship lock, a 23 sluice and consisted of 4×30MW bulb tubular units [6].

With the cascade development, channel expansion and function upgraded, the end of the downstream of Changsha Navigation and Hydropower Complex of Xiangjiang River (9th level) and Tugutang Navigation and Hydropower Complex (6th level) has built fishway. Zhuzhou Navigation Complex (8th level) and Dayuandu Navigation and Hydropower Complex (7th level) are also planned to build fishway simultaneously at the 2000t second-tier shiplock construction and are scheduled to be completed in 2018.

Fishway construction is not only for the protection of fish, but also to maintain the river channel connectivity, to provide important technical means to compensate for the negative impact from dam obstruct [7]. The program of the fishway project has a great difficulty. At the basic of full guarantee of the effect of the fish pass, the scheme is not only necessary to coordinate the existing shiplock, sluice and power station, but also need to consider the relationship with the new second-class shiplock.

2. Mainly fish objects and seasons

2.1 The fish pass objects

Dayuandu Fishing engineering focuses on the fish over dam problem with migration between the river and lake and the short-distance migration characteristics, taking into account all the fish distributed by migration between the salt-fresh water and dam site. According to The feasibility study report about navigation ecological restoration construction of (The fishway engineering of Zhuzhou Navigation and Hydropower Complex and Dayuandu Navigation and Hydropower Complex), the main fish pass objects in Da Yuandu hub is in Table 1.

| Fish name                          | Migration type       | Resource status          | Fish protection | Commercial fish |
|------------------------------------|----------------------|--------------------------|-----------------|-----------------|
| Herring, grass carp, Silver carp, Bighead carp, Bream, Silver Xenocypris | Migration between the river and lake | | √ | |
| Head bream, Triangular bream, Mystus, Yellow-eyed Xenocypris, Erythrina, Cunninghamia erecta, Southern catfish et al | Short distance migration | | √ | |

2.2 Fish pass season

The location of the hub is the section for hatching zygote of Xiangjiang River, and about 90km on the dam is "the four major Chinese carps" (green, grass, silver carp, bighead carp) spawning ground, which is known to be one of the three "domestic fish" spawning ground in China. Therefore, the "the four major Chinese carps" breeding migration must pass through the dam. This river was the section
for salvage fish eggs of Xiangjiang River before the complex construction, many varieties of fish gathering under the dam during the breeding season. According to the study of fish in engineering section, fish pass object in this fishway is mainly fish with the migration between the river and lake and short-distance migration characteristics, while taking into account the distribution of brackish water and the distribution of other fish, the main breeding and spawning period of Xiangjiang river fish is March to July, therefore, a comprehensive determination of the fish pass period for each year is March to July.

3. The arrangement scheme of fishway entrance

According to the multi-year operation and dispatching scheme of Dayuandu Junction, the lowest operation water level water level is 40.89m in the lower reaches of the fishway while the maximum running water level is 43.30m, and the guarantee rate of fish passage season can up to 90%. The lowest operating water level is 48.40m in the upper reaches of the fishway while the maximum water level is 50.10m, and the guarantee rate of the fish season can up to 98%. The maximum waterhead of this fishway project is 50.10 - 40.89 = 9.21m. According to its structural type and hydraulic characteristics, fishway can be divided into transverse diaphragm type fishway, the original ecological fishway, slot type fishway and special structure of the form of fishway, etc. Horizontal plate type fish trapezoid type can be divided into overflow weir type, submerged hole type, vertical seam type, combined type [9]. To facilitate the fish in the migratory channel to rest, with the consideration of fish pass type, energy absorbing capacity, flow conditions, structure form, combined with fish with weak swimming ability and relatively small size [10], this article use the horizontal diaphragm vertical sewn fishway structure [11], and set up fishing facilities, observation room, etc.

3.1 Layout

Combined with the new Dayuandu crossing second-line lock project layout and implementation, the fishway project has proposed two planar layout schemes (Fig.1).

Scheme 1 (in the right bank power station side): the entrance is arranged in about 350m downstream the power plant; it makes use of the power station tail water discharge flow rate to induce fish. Scheme 2 (in the left bank of the river island (Empty Island)): the entrance closes to the end of the Xingjiang River and the Mishui river convergence area; it takes advantage of the combination of convergence flow rate and replenishment channel to induce fish; the total length is 1552.9m.

3.2 Comparison for different cases

Compare: Based on the SMS-RMA2 model developed by the Environmental Laboratory of Brigham University in the United States, a mathematical model of planar two-dimensional hydrodynamic model along the average depth of water is established for the simulation of the water flow characteristics of Dayuandu Navigation and Hydropower Complex nearing the downstream of the dam.
Through the numerical simulation of the model of the two cases under the different conditions, comparing flow field diagram of the two scheme, and choosing 6 groups of flow field of the dry season to analyze, as shown below.

![Flow field under different discharge flow in dry season.](image)

Table 2 Entrance flow velocity under different conditions in normal and dry season

| Discharge (m$^3$/s) | Generating Units | Units Discharge (m$^3$/s) | The number of the opening drain holes | Sluices opening situation | Whether the import flow conditions are met |
|---------------------|-------------------|-----------------------------|---------------------------------------|---------------------------|--------------------------------------------|
| Dry Season          |                   |                             |                                       |                           |                                            |
| 150                 | 1                 | 150                         | /                                     | All closed, the power station discharging and generating | No                           |
| 300                 | 1                 | 300                         | /                                     |                           | Yes                                        |
| 520                 | 2                 | 520                         | /                                     |                           | Yes                                        |
| 800                 | 3                 | 800                         | /                                     |                           | Yes                                        |
| 1150                | 4                 | 1150                        | /                                     |                           | Yes                                        |
| 1912                | 5                 | 1912                        | /                                     |                           | No                                         |
| Normal Season       |                   |                             |                                       |                           |                                            |
| 3050                | 5                 | 1500                        | 3-14#                                 | Some gates of sluices be opened, power station in normal operation and discharging normal flow | No                           |
| 4150                | 5                 | 1240                        | 3-23#                                 |                           | Yes                                        |
| 5300                | 5                 | 1080                        | 3-23#                                 |                           | No                                         |
| 6450                | 0                 | /                           | 1-23#                                 |                           | Yes                                        |
| 7100                | 0                 | /                           | 1-23#                                 |                           | No                                         |
| 7950                | 0                 | /                           | 1-23#                                 |                           | No                                         |

Note: " / " means the generating units or sluices are not opening or discharging.

According to the experiment and observation data, the proper flow velocity of "the four major Chinese carps" is between 0.3m/s~0.5m/s. Excluding the physical reason of fish, the limit velocity is about 1.0m/s. The empirical formula is used to estimate the swimming ability of fish:

$$\frac{1}{2}L^{1.98}V$$

Where:

- **V**: velocity that can be overcome by fish (m/s)
- **L**: the length of fish (m)

The average velocity in the fishway ranges from 0.3m/s~0.5m/s. Induced velocity is 0.2m/s. Limit velocity is 1.3m/s, the calculated controlled entrance flow velocity is between 0.2m/s~1.3m/s$^{[11]}$. 

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Table 3 Comparison of fish pass capacity between Case 1 and Case 2 under different commissioning modes

| Discharge (m³/s) | number of machines in operation | Units Discharge (m³/s) | The downstream water (m) | Sluices opening situation | Case 1 | Case 2 | Comparison result |
|------------------|--------------------------------|------------------------|--------------------------|---------------------------|--------|--------|-------------------|
|                  |                                |                        |                          |                           |        |        |                   |
| Dry season       |                                |                        |                          |                           |        |        |                   |
| 50               | 1                              | 150                    | 39.50                    | /                         |        |        | Case 2 is superior |
|                  |                                |                        |                          | Followed by a large range of low velocity zone, the fish cannot find the fish inlet easily |        |        |                   |
|                  |                                |                        |                          | Suitable for fishway entrance layout |        |        |                   |
| 300              | 1                              | 300                    | 40.20                    | /                         |        |        | Both feasible     |
|                  |                                |                        |                          | Followed by a certain range of low velocity zone, the fishway layout can avoid the region |        |        |                   |
|                  |                                |                        |                          | Suitable for fishway entrance layout |        |        |                   |
| 520              | 2                              | 520                    | 41.00                    | /                         |        |        | Case 1 is slightly superior |
|                  |                                |                        |                          | All closed the power station discharge |        |        |                   |
|                  |                                |                        |                          | Suitable for fishway entrance layout |        |        |                   |
| 800              | 3                              | 800                    | 41.30                    | /                         |        |        | Case 1 is slightly superior |
|                  |                                |                        |                          | Suitable for fishway entrance layout |        |        |                   |
| 1150             | 4                              | 1150                   | 41.60                    | /                         |        |        | Case 1 is slightly superior |
|                  |                                |                        |                          | Followed by a certain range of high velocity zone, the fishway layout should avoid the region |        |        |                   |
|                  |                                |                        |                          | Fish measures should be taken |        |        |                   |
|                  |                                |                        |                          | Both feasible     |        |        |                   |
| 1912             | 5                              | 1912                   | 42.40                    | /                         |        |        | Case 2 is superior |
|                  |                                |                        |                          | Fish measures should be taken |        |        |                   |
| Normal season    |                                |                        |                          | Both feasible     |        |        |                   |
| 3050             | 5                              | 1500                   | 43.30                    | 3~14#                     |        |        | All feasible       |
|                  |                                |                        |                          | Part of the sluice open, Power station turbine discharge |        |        |                   |
|                  |                                |                        |                          | Fish gathering measures should be taken |        |        |                   |
| 4150             | 5                              | 1240                   | 44.20                    | 3~23#                     |        |        | All feasible       |
|                  |                                |                        |                          | Fish gathering measures should be taken |        |        |                   |
|                  |                                |                        |                          | Suitable for fishway entrance layout |        |        |                   |
| 5300             | 5                              | 1080                   | 44.80                    | 3~23#                     |        |        | Case 2 is superior |
|                  |                                |                        |                          | Fish gathering measures should be taken |        |        |                   |
|                  |                                |                        |                          | Suitable for fishway entrance layout |        |        |                   |
### Table 1: Discharge, Number of Machines in Operation, and Sluice Opening Situation

| Discharge (m³/s) | Units Discharge (m³/s) | The downstream water (m) | The number of sluices opening | Sluice opening situation | Case 1 | Case 2 | Comparison result |
|-----------------|------------------------|--------------------------|------------------------------|-------------------------|-------|-------|-------------------|
| 6450            | 0                      | 45.80                    | 1~23#                        | Followed by a flow barrier across the main river, fish cannot reach the entrance | Suitable for fishway entrance layout | Case 2 is superior |
| 7100            | 0                      | 46.50                    | 1~23#                        | Followed by a flow barrier across the main river, fish cannot reach the entrance | Suitable for fishway entrance layout | Case 2 is superior |
| 7950            | 0                      | 47.50                    | 1~23#                        | Followed by a flow barrier across the main river, fish cannot reach the entrance | Suitable for fishway entrance layout | Case 2 is superior |

Figure 2 and table 2 show that in the dry season, the right side of riverbank will emerge from the water, and the main channel is relatively narrow. With 1 generator unit with 150 m³/s power flow discharge, the No.2 inlet velocity of Case 2 is not lower than 0.2 m/s, while nearing the upstream existing the low velocity zone across the main River, whose velocity is less than 0.2 m/s. So, the fish is easily to trace the No 2 entrance. In the period of normal season, the discharge is larger than 5300 m³/s, nearing the No.2 entrance upstream existing a flow rate barrier across the main river, whose velocity is more than 1.3 m/s, when the fish is retreated, the entrance can be found more easily. A comprehensive study shows that when the discharge is between 150~7950 m³/s, the No.2 inlet flow conditions meeting the requirements of flow velocity between 0.2 m/s ~ 1.3 m/s [13] in every condition in dry and normal season. Therefore, judging from flow conditions, Case 2 is fully meet the requirements of the fish pass. Combined with the layout and entrance site of additional fishway construction, case2 is the better choice.

In case 1, when there is one unit power generation in the hub with 150 m³/s discharge and hub discharge is greater than 5300 m³/s, the flow velocity in main channel is too small or too large, which cause the fish would not be able to find the inlet; when the discharge is between 300 m³/s ~4150 m³/s, the velocity and water depth of the entrance comply with the requirements of the fishway layout. After taking the measures accordingly to lure fish and water, all conditions can meet the requirements of fishway entrance layout. Considering there are some difficulties in fish sail upstream under the condition of small and large discharge, and there is some influence on the complex of the influence of seepage prevention system, comprehensively analyzed, Case 2 would be a better option.

#### 3.3 Main problems
Case 2 the corresponding fishway entrance can meet the requirements of 0.2 m/s ~ 1.3 m/s under the conditions of the discharge downstream flow of 150 ~ 7950 m³/s during the dry season, when the discharge downstream flow is 300 ~ 4150 m³/s, the flow velocity in most parts of the main channel is also between 0.2 m/s ~ 1.3 m/s, and the flow conditions are suitable for fish pass. At this time, the entrance is relatively smaller than the main channel, showing no "entrance" of practical meaning; then fish is likely to go upstream to the main channel without entering the fishway entrance. This scheme has a problem that the location of the fishway entrance is not obvious, which need to take the optimization measures at the entrance.

#### 4. Optimization of fishway entrance
The main goal of optimization: Fish pass objects in the case of 300 ~ 4150 m³/s flow can easily find
the fishway entrance; therefore, following optimization measures can be taken:

1) Add an electrode type of block fish system upstream of the fishway. At present, there are some common barring fish establishment in construction: block dam (weir), block, the electrode type of barring fish system, etc. Considering the fishway entrance is located under the sluice dam discharge gate dam, an electrode - type of barring fish system is chosen, it has the advantages of the capability for resistance current, the capability for passing floatation, convenient management and maintenance and so on. The spacing and diameter of electrodes are determined by the factors such as the block fish object, water conductivity, the electric grid length and the pulse generator, the aim is to design a reasonable electric field instead of damaging fish, but the fish will be able to sense the electric field soon and distinguish the escape route and direction, to the weak electric field, and then find the entrance of fishway.

2) Acoustic induced system is arranged in the fishway entrance. A single row electrode type is adopted for the sound trapping fish system, consisting of two 50m span units. A sling is placed at the main cable every 10m, the distance between the electrodes is 3m, and the galvanized iron tube with a diameter of 8.3cm is used. The distance between the system and the fishway entrance is 3~5m, and its intersection angle with the mainstream is about 75°.

The system mainly make use of water flow and underwater sound to work. Taking artesian water from the upstream approach channel through the piping system, and water flows along the side wall to the fishway entrance, after the inlet pipeline with different diameter fishway to form a sprinkler system. The luring fish system is assisted by the sound of artesian drip. Acoustic induced system can better induce fish, after the migration path is affected by the system, fish can find the fishway entrance more quickly.

5. Conclusion
In this study, the Dayuandu Navigation & Hydropower Complex in Xiangjiang is taken as the investigative object. The arrangement types and optimization measures of the entrance of fishway are discussed; some main conclusions are given as follows:

1) The river where Dayuandu Navigation and Hydropower Complex of Xiangjiang locate in is the hatch zone for "the four major Chinese carps" and the spawning ground. The breeding season (March to July) is considered the main fish pass season. Based on the induced velocity, fish preferred velocity, limit velocity analysis, the most proper velocity for "the four major chinese carps" is 0.2m/s~1.3m/s.

2) Generally, fishway entrance designed at the downstream of power station, but most fishway flow cannot meet the requirements of 0.2m/s~1.3m/s optimal flow velocity. According to Case 2, The entrance disposed on the river island, using the conflux area of Xiangjiang and the Mishui River for fish luring. But in most discharge cases, a wide range of places in the river can meet the best flow rate requirements for fishway entrance, thus the selected fishway entrance does not show the actual meaning of "entrance", which need to take the necessary measures for optimization. Therefore, the study of the flow conditions of the fishway entrance water cannot be concerned only with the flow conditions at the entrance, but also the water flow in other areas of the river.

3) Fishway entrance arrangement and fish luring is the key to fishway design. The usage of electrode-type barring fish system and acoustic induced system in the upstream of fishway is conducive to the improvement of entrance conditions, and convenient for fish to find better inlet.

4) This study provides some reference for similar projects such as the arrangement of the fishway project, the location choices and optimization measures of the entrance of fishway.

5) The fishway layout scheme, entrance site selection, and optimization measures of the fishway project will provide some reference for similar projects especially the additional construction of fishway.

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