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Analysis on the Flows in a Pool of Stepped Fishway

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ABSTRACT

In this paper, the authors examined techniques for analyzing flows in a fishway pool with a variety of shapes. By comparing the calculated flow field with the observed flow field in an actual fishway and a fishway proposed by the authors, it was shown that the calculated results for flow pattern agree with actual measurements. It is possible to examine the shape of fishway by using numerical simulation on flow field in a fishway-pool.

Key words: stepped fishway, flow in a pool, numerical simulation

1. Introduction

In river projects, designs conducive to the upstream migration of fish are being promoted for the purpose of protecting river ecosystems and river environments, while existing weirs and other hydraulic structures that obstruct the upstream and downstream movement of fish are being fitted with fishways. However, a conventional fishway is designed empirically, by determining fish's swimming-strength relative to representative velocity at the overflow portion; it is not clear whether conventional fishway is appropriate for the fish and whether it will be conducive to the fishes' upstream migration in real. Instead, the upstream migration characteristics of the fishway are determined empirically, from the number of fish that actually travel upstream through it.

It is therefore necessary to ascertain what type of fishway flow characteristics are preferable with respect to fish behavior, and then determine the fishway shape that will generate this type of flow. Techniques for determining the relationship between fishway shape and flow field include hydraulic model experiment and numerical simulation. The disadvantage of hydraulic model experiment is the labor and time required to measure the flow field and to change fishway shape. Instead, numerical simulation of the flow field in fishway pools should be a valid means of determining, to a certain extent, fishway structure and shape.

For this paper, the authors, choosing stepped fishways (a common type in Japan) as the subject of analysis, performed field measurement on actual fishways and hydraulic model of fishway their proposed fishway shape. In addition, numerical subject was then used with this field-measurement and model experiment in order to assess the validity of the numerical analysis of flows in fishway pools.

2. Shapes of Conventional Fishways and a Fishway Proposed by the Authors

Conventional fishways are assessed and designed using wall height, representative velocity, and other indicators that indicate only whether upstream fish migration is possible in terms of fish swimming strength; fish behavior and specific flow conditions inside the fishway, for example, are not taken into consideration. Thus, in such cases it is not clear what type of rational fishway design would be truly conducive to upstream migration. Consequently, a variety of fishways, based on various shape-related innovations, have been constructed. These fishways can be assessed in terms of whether fish are actually migrating upstream, but it is difficult to determine which of these many fishway designs is superior.

Here we shall describe the characteristics of a fishway we have designed to suit the behavioral characteristics of the smellfish (Nakamura et. al. [1],[2]), the subject of this work. Fig. 1 is an example of a stepped fishway, a ubiquitous type. Fig. 2 is the fishway proposed by the authors, and is characterized by the following.

1) A section in the center where the water does not overflow, and a section in the back where the flow is slow.
2) Water surges up from the bottom, guiding the smellfish to the proximity of the overflow portion.
3) The overflow depth on the wall varies transversely, permitting individual smellfish to select a velocity suited to its specific swimming strength.

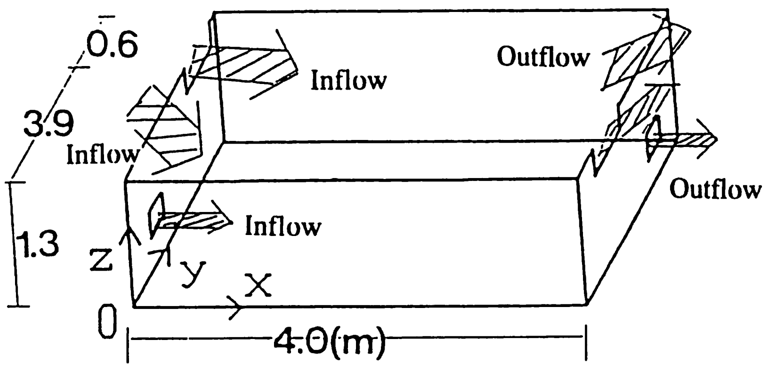

Fig. 1. An example of an actual stepped fishway

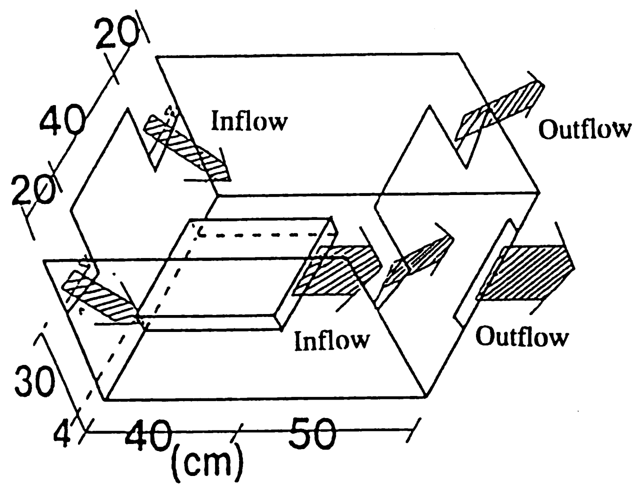

Fig. 2. an example of the fishway proposed by the authors

3. Numerical Analysis Method

The flow in a fishway has three-dimensional features. It has a free surface and complex conditions involving inflow to and outflow from weirs and submerged openings. Here, we shall determine the flow field of stepped fishways using the SMAC method, which involves solving a continuity equation and equation of motion simultaneously.

The basic thinking behind this analysis is as follows.

A fishway is generally composed of multiple levels of successive pools. Although it would be preferable to determine the flow for the enter group of these pools, the required calculations would be considerably time-consuming, and it would be difficult to calculate free-falling water streaks between pools. We therefore decided to perform the calculations on one representative pool only, and, with respect to free-falling water streaks, to assign dominant cross-sections at the inflow and outflow portions to create boundary conditions in which the flow there depends on external conditions. Actual measurements were chosen as the values used to express the conditions of the free-falling water streaks from the weirs and the flow at the submerged openings. Measurements were also used for surface height. A fixed surface height was used in order to enhance stability and convergence in numerical analysis, and pressure was determined from surface position. The conventional SMAC scheme was used, and upwind conversion was performed using primary accuracy (Takahashi [4]).

The procedure for using the SMAC method is as follows. First, the tentative velocity, v', is determined.

$$v' = v^n + f(v^n, p^n)dt$$

Next, the divergence of v' is calculated to determine adjusted pressure dp.

$$\mathrm{div} \bullet \mathrm{grad}(dp) = \mathrm{div}(v'/dt)$$

Last, the velocity is adjusted.

$$v^{n+1} = v' - \mathrm{grad}(dp)dt$$

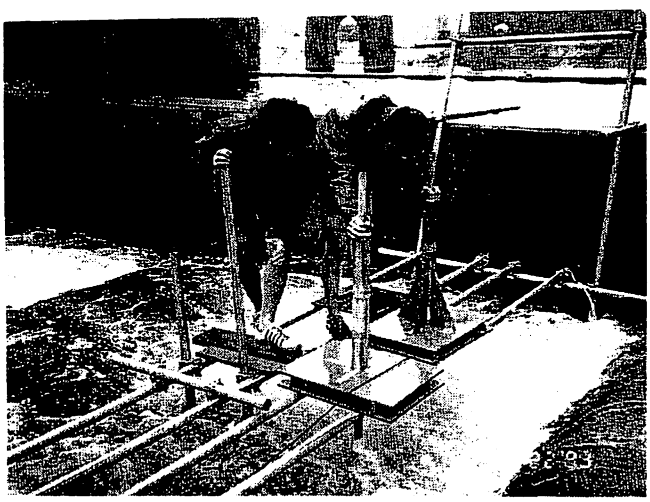

Photo. 1 Situation of field measurement

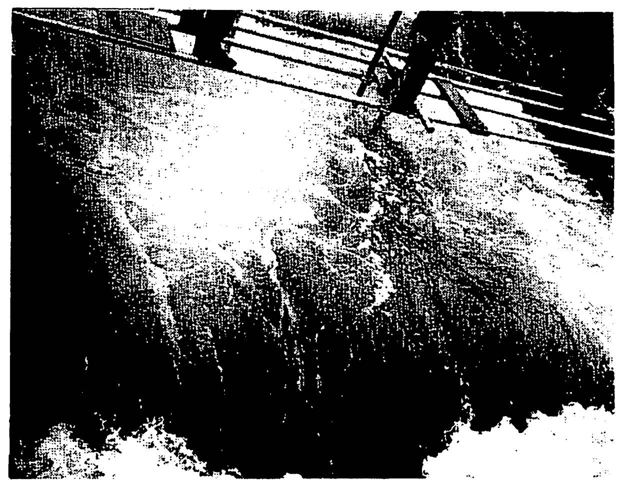

Photo. 2 Situation of flow in a pool

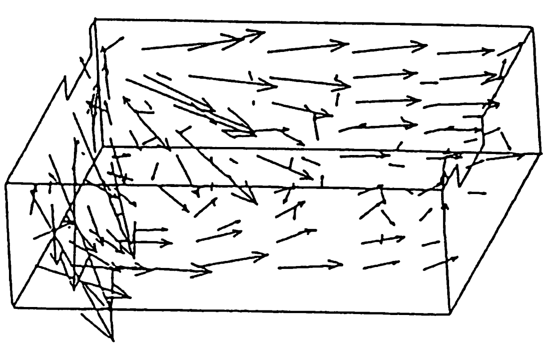

Fig. 3. The results of field measurement

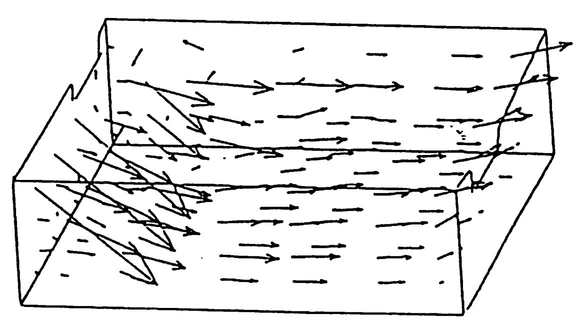

Fig. 4. The results of numerical analysis

4. Comparing the Calculated Flows with the Observed Flows in a Actual Fishway Pool

Here we discuss flows in the fishway shown in Fig. 1, a stepped fishway with notches and submerged openings arranged alternately. Notch width is 1.25 m; depth, 0.1 m. The pool portion is 4.0 m long and 4.5 m width, with a vertical interval of 0.25 m. The measured overflow depth was 0.2 m, and velocity in the overflow portion was about 2.0 m/s. Photo 1 shows measurements being performed on the actual fishway. Photo 2 shows the flow inside the pools.

Figs. 3 and 4 show the velocity vector distributions given from field measurement and numerical analysis, respectively. As Photo 1 shows, field measurement was performed using two-element electromagnetic velocity meters (one for u&v and one for u&w); the 30 seconds and 60 seconds averages of the velocity were calculated in order to express this three-dimensional velocity vector. Because the actual flow fluctuated considerably over time, in our analysis we shall focus on the average flow field.

The grid intervals used in this analysis were dx = 15 cm, dy = 15 cm, and dz = 8 cm. The time interval is 0.01 s. For the calculations an initial condition of resting was assigned. Startup calculations on 20 seconds of the velocity at inflow and outflow portions (the boundary conditions) were performed, after which consistent boundary conditions were assigned. The calculated conditions after 30 seconds, when the flow field was nearly in equilibrium, were used as the calculated value.

Fig. 3 shows the slow water area in the center of the fishway. As Photo 2 shows, there are considerable bubbles between the center of the pool and the intrusive portion of the free-falling water.

A comparison of Figs. 3 and 4 shows that the results of numerical analysis generally agree with flow conditions in the actual fishway. There is, however, slight difference in velocity distributions near the overflow portion: although the measurements show a large, fairly complex eddylike flow in this area, numerical analysis reveals no such flow. See Figs. 5 and 6 to compare the measured and calculated flow conditions in the cross-section of t he un-notched and notched sections. The reason for this difference is believed to be the following.

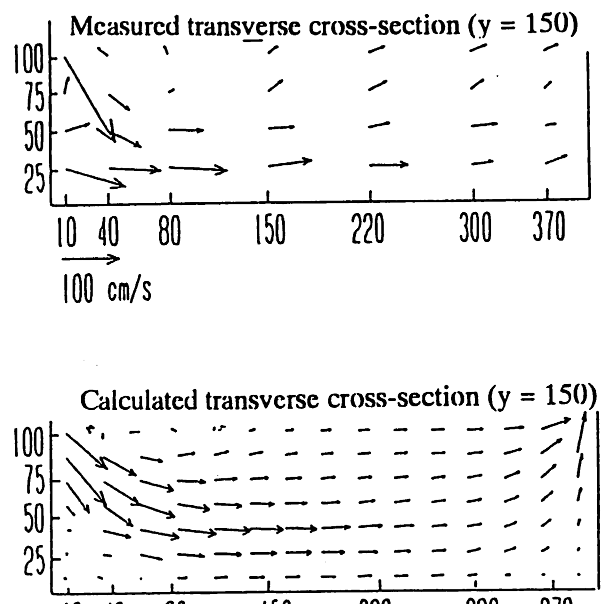

Fig. 5. A comparison of observed and calculated cross-sectional flow in the non-notched section

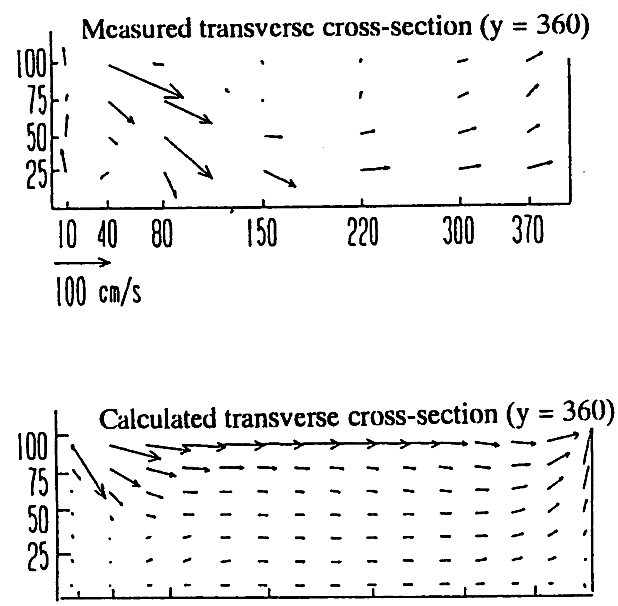

Fig. 6. A comparison of observed and calculated cross-sectional flow in the notched section

The velocity vector, which is the boundary condition for t he inflow portion, has a considerably large effect on the flow in the fishway, which makes it very important to assign the proper boundary conditions to create the fishway flow field. Hence, experimentation and other techniques to further reveal conditions in this section are essential. Factors such as large spaces in the divided grid and the low degree of differential accuracy may be responsible for the calculated flow's differing from the actual fishway's in that the former is too smooth (Fig. 6). One possible factor not incorporated into this analysis is the effect of the bubbles transported in the water. In the actual fishway, the considerable amount of bubbles seemed to be inducing an ascending current. These factors are believed to be responsible for the difference in flow fields near the surface.

5. Comparing the Calculated Results and Model Experiments with Respect to the Flow in the Proposed Fishway

Let us now compare the results of numerical analysis and model experiments on the flow field of the proposed fishway aforementioned Fig.2. In the model experiment shown in Photo.2, velocity was measured with an electromagnetic velocity meter. The grid intervals for the calculations were $dx = 2$ cm, $dy = 2$ cm, and $dz = 1.5$ cm; the time interval, 0.015 s. For velocity in the shallow overflow portion, measurements obtained with a Pitot tube were used. Depth in the overflow portion was 4 to 5 cm; velocity, roughly 70 to 90 cm/s. See Figs. 7 and 8 for the experimentally obtained and calculated three-dimensional velocity vector distribution of the fishway.

Comparing Figs 7 and 8, we see that the calculated results generally agree with the experimental results. Particularly well-recreated are the flow elements that take smellfish behavior into account; namely, the slow flow at the back of the wall (section A), the large velocities downstream from the submerged openings (section B), the backflow below the inflow portion (section C). Nevertheless, a closer comparison reveals differences in the two velocity distributions. Because of the low volume of air in the experimental flow and the consequently limited effect of bubbles, these differences are believed to originate in problems with the model used in numerical analysis. In particular, the effects of the inflow portion's boundary conditions is, as mentioned above, extremely large, making it necessary to accurately assign the inflow portion flow used as the boundary conditions. The large volume of three-dimensional calculations uses a large amount of computer memory, and resulted in problems such as grid division being restricted by the computer's capabilities.

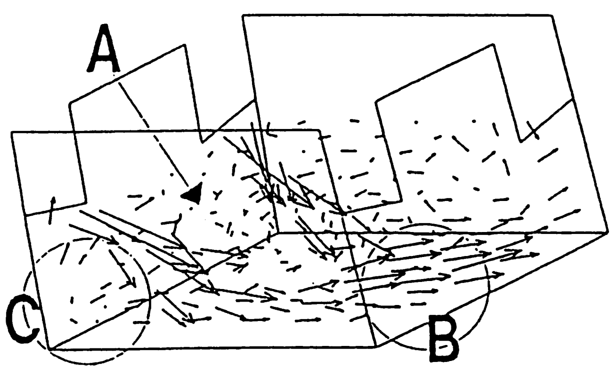

Fig. 7. The results of model experiment

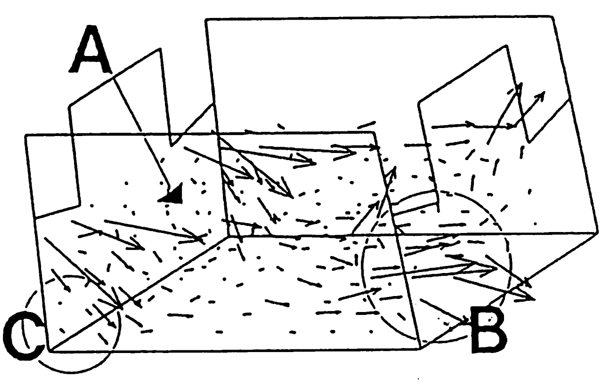

Fig. 8. The results of numerical analysis

Photo 4 shows observation of the experiment, in which fishery-bred young smell fish 5 to 7 cm long were released into the fishway shown in Fig. 2. The smellfish clustered near the overflow portion and at the bottom; some traveled upstream.

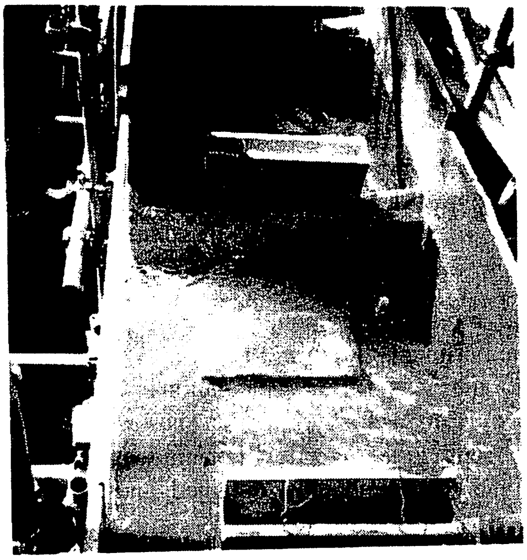

Photo. 3 Hydraulic model of fishway

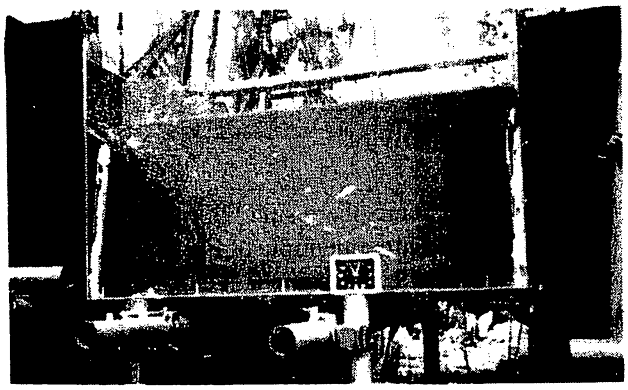

Photo. 4 Experiment on the fish's movement

6. Conclusion

This paper has shown that when factors like water level and velocity distribution at the inflow and outflow portion are assigned as boundary conditions, the results of numerical analysis nearly correspond to actual flow conditions in fishway pools. This suggests that this numerical analysis technique should be capable of similarly recreating flow conditions not just in the type of fishway used here, but also in ordinary stepped fishways and Ice harbor-type fishways.

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