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About the Effectivity of the Priming Water Channel in the Pool-and-Weir-Fishway

EFFECTIVENESS OF PRIMING WATER CHANNEL IN POOL-AND-WEIR-FISHWAY

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ABSTRACT

The number of fish swimming toward a fish-way increases when priming water is added. The function of the priming water is to lead fish toward the fish-way, and therefore, its addition becomes a necessity. However, a circulation flow is sometimes formed at the downstream. By setting up a division wall between the priming water channel and the main channel, we cancel the circulation flow, thereby increasing the run-up and leading ratios. In addition, the run-up ratio reaches its highest point when the priming velocity is three times the overflow velocity. Moreover, when magnitude of the overflow velocity becomes approximately seven times the number of the length of a fish, the fish can easily enter through the fish-way.

Keywords: priming water, leading fish, pool-and-weir-fishway, circulation flow

1 INTRODUCTION

Until recently, the River Law had only considered water control and the utilization of rivers in Japan. However, it was revised in 1997. Articles concerning the river environment were included in the River Law in 2006 because nature-rich river management was required. Moreover, river planning is required to make the fish swim upstream easily.

Fish and crustaceans move in rivers in search for a spawning ground. However, they cannot move freely if cross structures such as weirs are installed. Therefore, in order to ensure the upstream and the downstream movement of fish and crustaceans, fish-ways must be installed. There are various types of fish-ways, such as pool type, stream type, and nature-rich type. In Japan, although pool-and-weir-fishways have been set up at various locations, many of these structures are old and dilapidated. The priming water channels are built adjacent to the fish-ways as a secondary structure in order to facilitate the function of the fish-ways. Figure 1 shows a typical pool-and-weir-fishway and a priming water channel.

There are numerous research papers solely concerning the hydraulic conditions in the fish-way. However, there are only few research papers on priming water. Further, hydraulic conditions suitable for the movement of fish in the fish-ways and priming water have not yet been discovered.

The purposes of this research are to examine the effectiveness and necessity of priming water. The research involves, a field study, experiments, and numerical analysis. The experiments were carried out to measure the flow at the downstream of the fish-way and to observe the movement of fish.

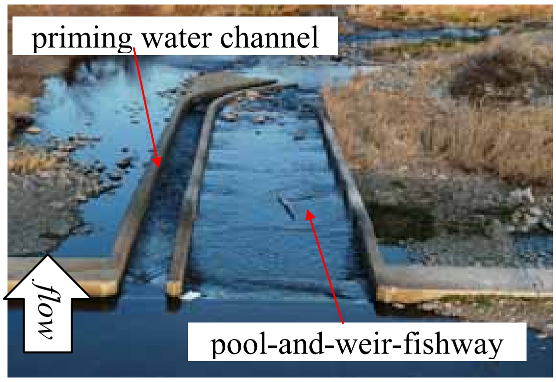


Figure 1 Pool-and-weir-fishway and priming water channel

2 PRIMING WATER

The purpose of adding the priming water is that it leads fish to the downstream entrance of the fish-ways. Generally, it is ideal for the priming water velocity to be twice the overflow velocity.

Function of priming water

The main function of the priming water is to lead the fish to the vicinity of the downstream entrance of the fish-way by increasing the flow of water. The functions of the priming water are to increase the region influenced by the flow at the downstream entrance of the fish-way and to lead the fish to the fish-way. They employ the unique movement of fish against the flow in order to enhance the efficiency of fish-ways.

Issue with priming water

Sometimes the flow of the priming water could have a harmful effect on the movement of fish. For example, when the priming velocity is considerably faster than the main velocity or the overflow velocity, a circulation flow is formed at the downstream entrance of the fish-way. As the result, fish cannot arrive at the downstream entrance of the fish-way and it is not possible for the fish to swim upstream. Figure 2 shows the circulation flow and the movement of fish in it.

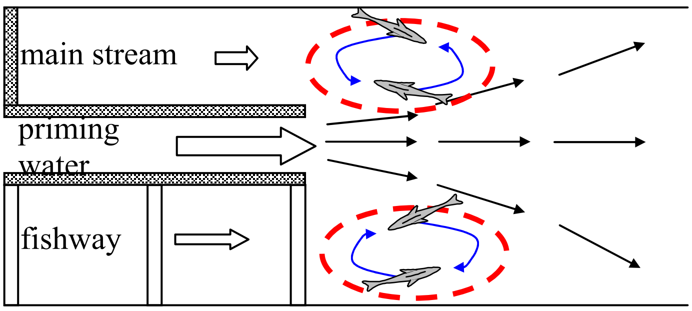


Figure 2 Schematic of circulation flow and movement of fish in it

3. FIELD STUDY

A field study was carried out in the Iruma River in Saitama Prefecture. Figures 3 and 4 show the location of the Iruma River, pool-and-weir-fishway, and priming water.

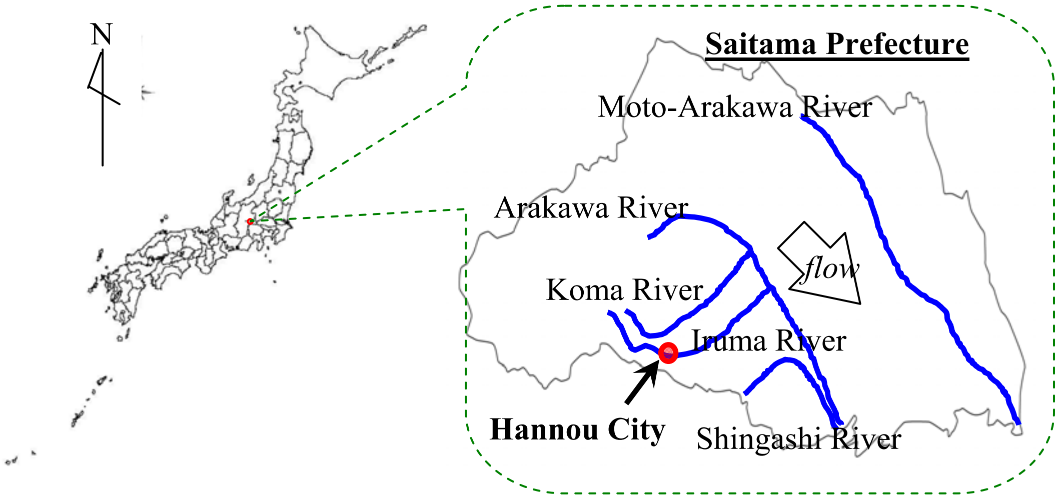


Figure 3 Location of the Iruma River

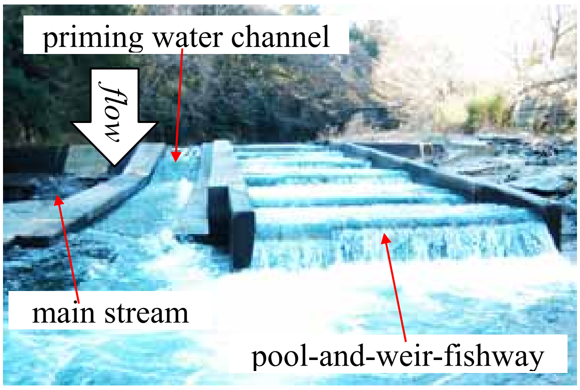


Figure 4(a) Structure of the fish-way

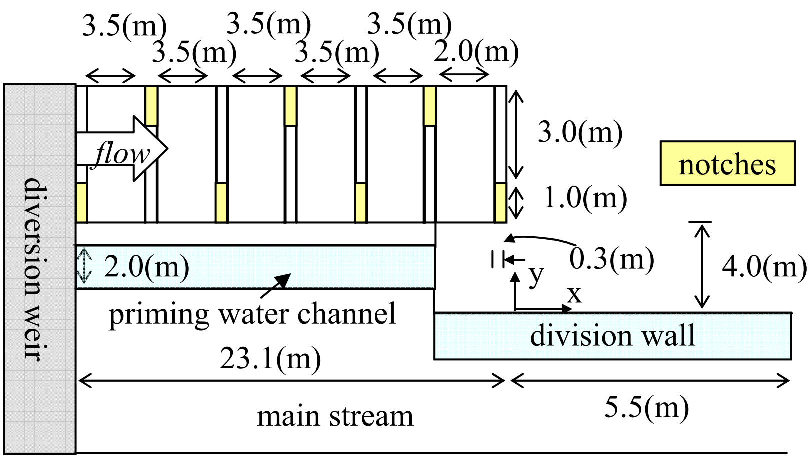
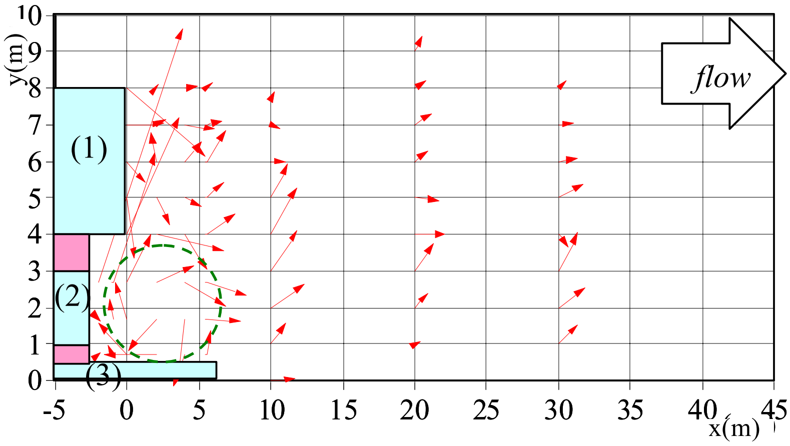


Figure 4(b) Plain view of the fish-way

Figure 4 Pool-and-weir-fishway and priming water in the Iruma River



(1) fish-way (2) priming water channel (3) division wall ——► 20 cm/s ◌ circulation flow

Figure 5 Flow in the downstream of the fish-way

The fish-way is a pool-and-weir-fishway and the notches are aligned in a zigzag manner. Moreover, the priming water channel is installed as a secondary structure. This fish-way is shorter than the priming water channel because the downstream pool was installed at a later stage. The drop between the downstream pool and the last fish step is significantly large. Therefore, the fish could not enter the fish-way.

Current condition of the pool-and-weir-fishway and the priming water channel

The priming water did not flow straight to the downstream region because part of the priming water channel was damaged. Further, the circulation flow was formed at the downstream of the fish-way. Therefore, the fish swam with the circulation flow. Because the fish could not swim upstream through the fish-way, it was concluded that the fish-way did not serve the desired purpose.

Confirmation of the type of fish

We performed a research on the biotic habitat of the river by visual observation, fishing, and underwater photography. We thereby confirmed the presence of various fish species such as *Tribolodon hakonensis* (body length: approximately 9 cm), *Zacco temminckii* (body length: approximately 6 cm), *Oncorhynchus mykiss*, and *Cyprinus carpio* only in the downstream of the division wall and main stream. Figure 6 shows photographs of fish found in the Iruma River. Further, the water quality corresponded to class B (fishery class 2) of the Environmental Quality Standards for Conservation of the Living Environment for rivers. Therefore, we are able to deduce that numerous types of fish are present in the Iruma River.

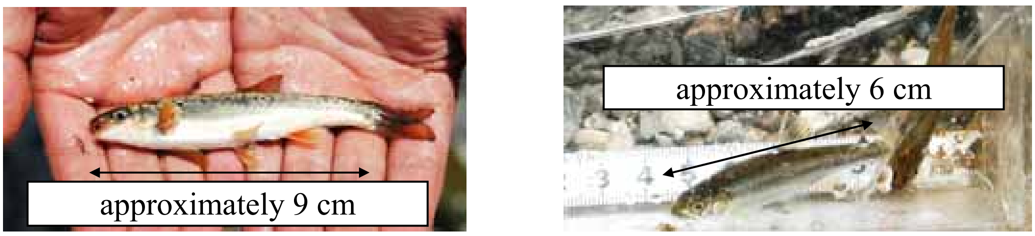


Figure 6(a) *Tribolodon hakonensis* Figure 6(b) *Zacco temminckii*

Figure 6 Fish found in the Iruma River

4. EXPERIMENTS

The experiments were carried out by using a small pool-and-weir-fishway in the laboratory of Toyo University. Figure 7 shows the model of the pool-and-weir-fishway used for the experiment. This fish-way has notches in zigzags at each bulkhead. Table 1 shows the cases considered in the experiment. The relationship between the effluent flow from the priming water channel and the movement of fish in the flow was researched. Ten *Tribolodon hakonensis* fish were used for the experiment.

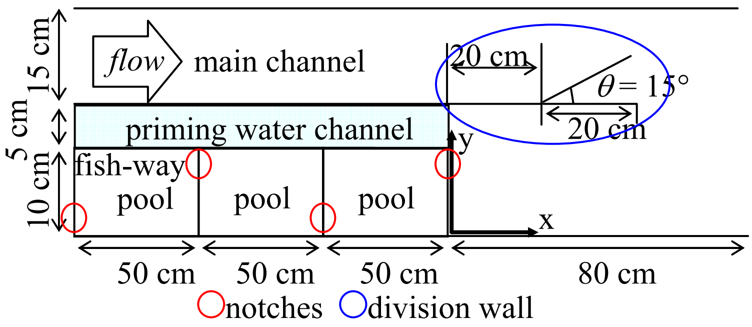


Figure 7(a) Plain view of the fish-way

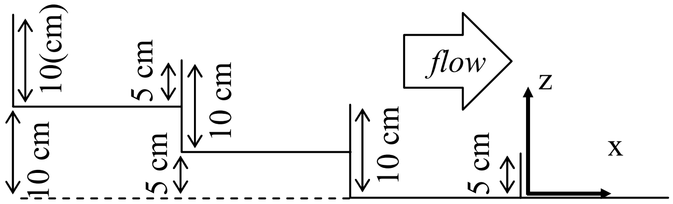


Figure 7(a) Sectional view of the fish-way

Figure 7 Model of the pool-and-weir-fishway for the experiments

Table 1 Cases considered in the experiments

	discharge (l/s)	priming water channel	division wall	angle θ
Case 1-1	0.5	not installed	-	-
Case 2-1	0.5	installed	0 cm	-
Case 3-1	0.5	installed	20 cm	-
Case 4-1	0.5	installed	40 cm	0°
Case 5-1	0.5	installed	40 cm	15°
Case 1-2	5.0	not installed	-	-
Case 2-2	5.0	installed	0 cm	-
Case 3-2	5.0	installed	20 cm	-
Case 4-2	5.0	installed	40 cm	0°
Case 5-2	5.0	installed	40 cm	15°
Case 1-3	7.0	not installed	-	-
Case 2-3	7.0	installed	0 cm	-
Case 3-3	7.0	installed	20 cm	-
Case 4-3	7.0	installed	40 cm	0°
Case 5-3	7.0	installed	40 cm	15°

Flow in the downstream of the fish-way and fish movement

The run-up and leading ratios are defined in equations 1 and 2.

$$\text{Run-up ratio} = \frac{\text{Number of fish swimming upstream}}{\text{Number of fish used in the experiment}} \times 100(\%) \quad (1)$$

$$\text{Leading ratio} = \frac{\text{Total number of fish swimming toward the downstream entrance of the fish-way}}{\text{Total number of fish that attempted swimming upstream}} \times 100(\%) \quad (2)$$

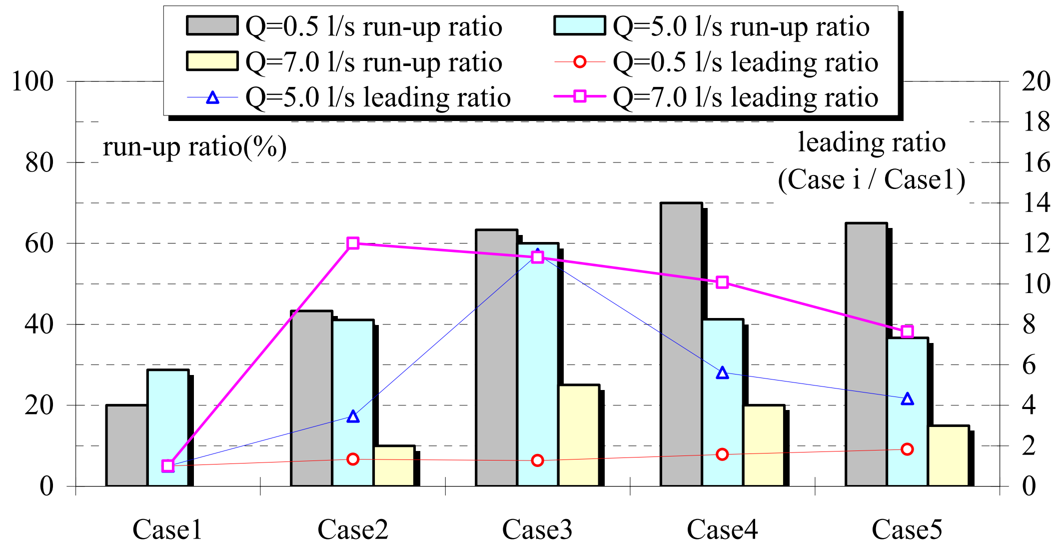


Figure 8 Run-up and leading ratios

Figure 8 shows the run-up ratio and leading ratios. The discharge in Cases 1-1–5-1 is Q = 0.5 l/s. By the same token, the discharge in Case 1-2–5-2 and Case 1-3–5-3 is Q = 5.0 l/s and Q = 7.0 l/s, respectively. The division wall was set from Case 2 to Case 5. Further, when the leading ratio of Case i is divided by that of Case 1, we obtain 1. In Case 1, without the priming water channel, the fish moved upstream in the main channel and remained there for a while, even though it was not the destination for the fish. In other words, the run-up ratio was small because fish could not move upstream in the fish-way. Moreover, the number of fish moving toward the downstream entrance of the fish-way increased when the priming water channel was installed. Further, the run-up ratio was higher than that in Case 1, which was without the priming water channel. The leading ratio was also higher than that in Case 1. However, the leading ratio did not change in the case of Q = 0.5 l/s. Fish could swim freely because the flow at the downstream of the fish-way became slower than the cruising speed that was fourfold from double the number of the length of a fish. Fish could swim upstream easily when the velocity was over four times the number of the length of a fish. Therefore, the priming water channel could not direct the fish to the fish-way. Moreover, the cases with Q = 0.51 /s assume the drought condition.

Figure 9 shows the velocity vector (Q = 0.5l/s). In the case without the division wall, the circulation flow was formed at the downstream of the fish-way. Figure 10 shows the velocity vector for Case 3-2 (Q = 5.0 l/s). In this case, the circulation flow was also controlled by the division wall. The number of fish moving toward the downstream entrance of the fish-way increased. Figure 11 show the velocity distributions in the transverse direction at the downstream of the fish-way.

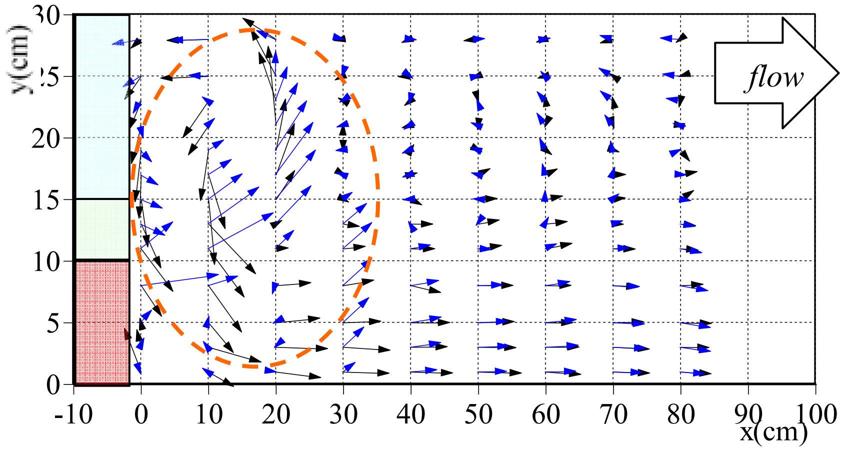


Figure 9(a) Case 1-1 experiment computed

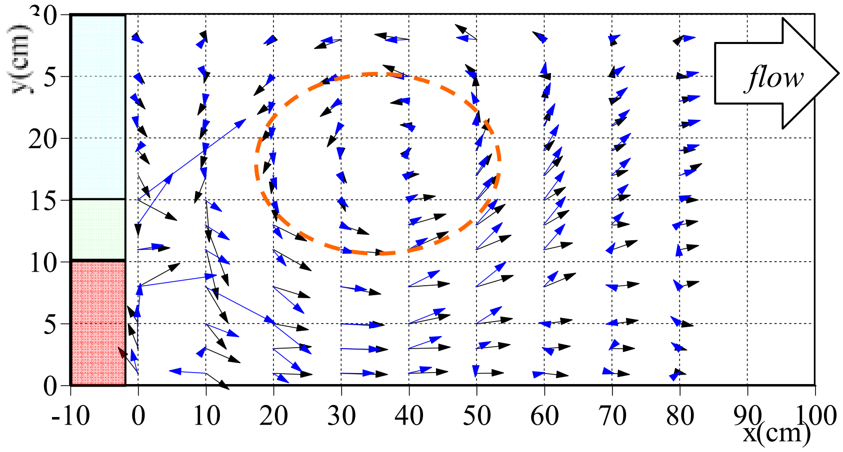


Figure 9(b) Case 2-1 experiment computed

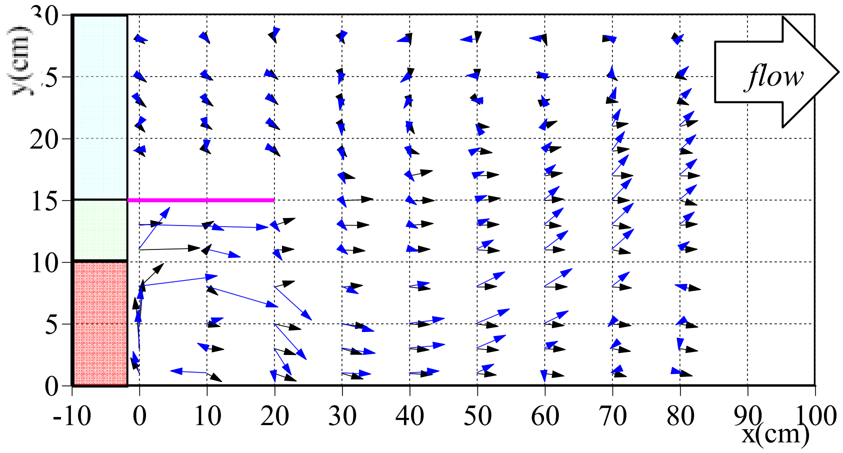


Figure 9(c) Case 3-1 experiment computed

main channel priming water channel fish-way division wall
circulation flow 10 cm/s

Figure 9 Velocity vector (Q = 0.5 l/s)

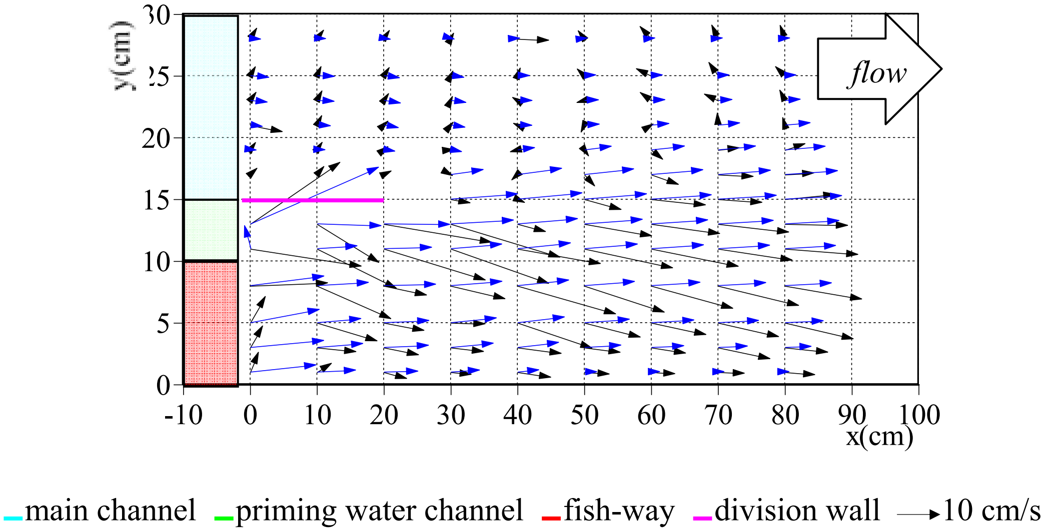


Figure 10 Velocity vector for Case 3-2 (Q = 5.0 l /s)

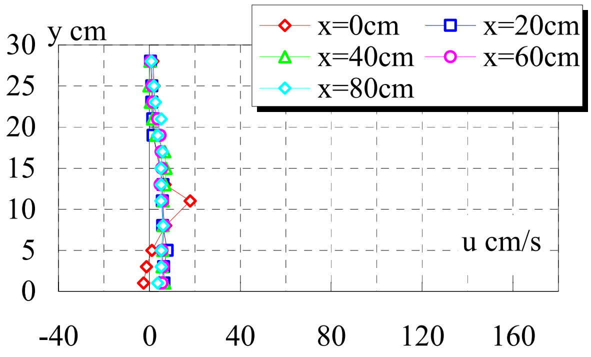


Figure 11(a) Case 3-1 (Q = 0.5 l /s)

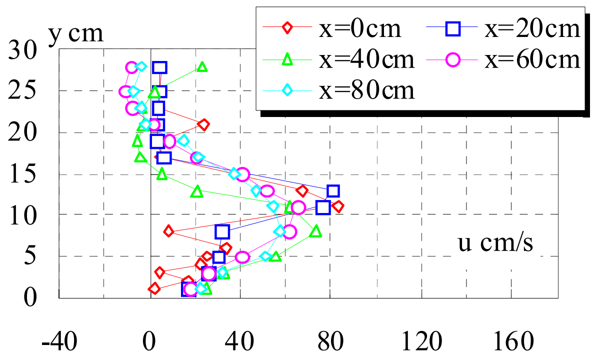


Figure 11(b) Case 3-2 (Q = 5.0 l /s)

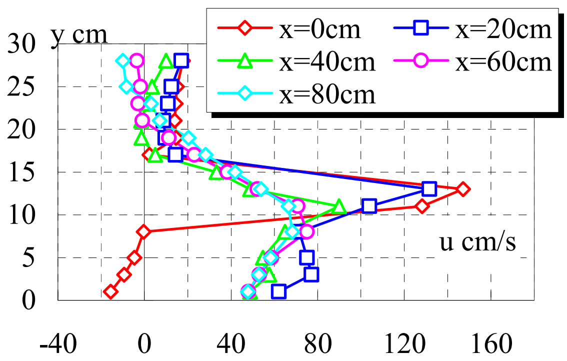


Figure 11(c) Case 3-3 (Q = 7.0 l /s)

Figure 11 Velocity distributions in transverse direction at the downstream of the fish-way

The priming water channel is essential for the easy movement of fish because it is constructed to lead fish to the downstream entrance of the fish-way. In addition, the division wall is also required. However, the priming water channel could not lead fish to the downstream entrance of the fish-way in the case of a small discharge. Moreover, when the discharge became too large, fish could not overcome the rapid flow and remained in the downstream. If the priming velocity became greater than the burst speed that was over 10 times the number of the length of a fish, the fish could avoid the rapid flow and move toward the downstream entrance of the fish-way.

Because it was very difficult to supply a constant discharge to the fish-way, the priming water channel had limitations to its function. However, the priming water channel assisted in leading fish.

Entry to the fish-way

In the experiments, the best result for fish swimming upstream was obtained in Case 3-2. In addition, the overflow velocity was nearly seven times the number of the length of a fish. In other words, fish easily entered the fish-way when the overflow velocity reached nearly seven times the number of the length of a fish.

5. NUMERICAL ANALYSIS

In order to reproduce the flow in the downstream of the fish-way, we used the two-dimensional shallow water equation and the equation of continuity. Equations 1 and 2 show the dynamic equation in the x and y directions. Equation 3 shows the equation of continuity.

Dynamic equation for the x direction

$$\frac{\partial M}{\partial t}+\frac{\partial uM}{\partial x}+\frac{\partial vM}{\partial y} = -gh\frac{\partial H}{\partial x}-\frac{gn^2u\sqrt{u^2+v^2}}{h^{\frac{1}{3}}}+\frac{\partial}{\partial x}\left(\varepsilon\frac{\partial M}{\partial x}\right)+\frac{\partial}{\partial y}\left(\varepsilon\frac{\partial M}{\partial y}\right) \tag{3}$$

Dynamic equation for the y direction

$$\frac{\partial N}{\partial t}+\frac{\partial uN}{\partial x}+\frac{\partial vN}{\partial y} = -gh\frac{\partial H}{\partial y}-\frac{gn^2v\sqrt{u^2+v^2}}{h^{\frac{1}{3}}}+\frac{\partial}{\partial x}\left(\varepsilon\frac{\partial N}{\partial x}\right)+\frac{\partial}{\partial y}\left(\varepsilon\frac{\partial N}{\partial y}\right) \tag{4}$$

Equation of continuity

$$\frac{\partial h}{\partial t}+\frac{\partial M}{\partial x}+\frac{\partial N}{\partial y}=0 \tag{5}$$

Here, u is the velocity in the x direction; v, the velocity in the y direction; $M(=uh)$, the flux in the x direction; $N(=vh)$, the flux in the y direction; h, the water depth; H, the water level; and ε, the eddy viscosity .

The flow in the downstream of the fish-way could be reproduced by computation. Although we used the two-dimensional shallow water equation, the accuracy of the flow was good. The calculated result is shown in figures 9 and 10.

6. SUMMARY

1) By installing the priming water channel, the number of fish moving toward the downstream entrance of the fish-way increases.

2) To control the occurrence of the circulation flow at the downstream of the fish-way, a division wall must be constructed. Hence, the number of fish moving toward the downstream entrance of the fish-way increases considerably.

3) For the priming water channel to function properly, the number of the priming velocity should be at least 10 times the number of the length of a fish.

4) To enable fish to enter the fish-way easily, the overflow velocity should be nearly seven times the number of the length of a fish.

5) By using the two-dimensional shallow water equation, the flow at the downstream of the fish-way can be clearly reproduced.

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