EFFECT OF DIFFERENCE IN SHAPE OF STEPPED FISHWAY ON FLOW STRUCTURE

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ABSTRACT

There are various structures such as the step type and the ice harbor type in the fishway, and the flow situation changes greatly depending on the structure, and it has a great influence on the habitat of fish. In this study, we focus on stepped fishways existing in the middle and downstream of real rivers, and examine how the difference in the structure of the fishway affects the turbulent structure. For the experiment, two different types of staircase fishway models are made and installed in an indoor open channel. Regarding the measurement of the flow velocity, the point measurement of the flow velocity by the type I electromagnetic anemometer and the simultaneous measurement of the flow velocity by the PIV method were performed. As a result, it was confirmed that a complicated flow occurred in the fishway with a structure of a submerged hole, and that the place where the fish going up rested was not clearly given. In addition, it was clarified that the turbulence characteristics changed greatly depending on the presence or absence of notches and holes, and the effect on fish run-up was great.

*Keywords*: Stepped fishway, turbulent structure, PIV

1.   INTRODUCTION

The fishway in the river channel is set up to protect the habitat of fish etc. when setting up river channel crossings. For this reason, it is necessary to consider under what conditions the number of fishes going up is high so that the fishway becomes more effective for fish going up. In addition, there are various structures such as the stairway type and the ice harbor type in the fishway, and it is thought that the number of run-ups varies depending on the structure.

A parameter that is important when considering fish run-up is the cruising speed. This is an indicator of swimming ability and is a measure of the flow rate at which fish can rest in the fishway. According to Brett et al. (1958), the definition is the maximum speed at which a swim can last for 60 minutes. Therefore, it is necessary to understand the details of the flow in the pool in the fishway. Among them, Rajaratnam et al. (1988) examined the state of the flow in the pool and pointed out that the flow can be classified into two types, plunging flow and streaming flow. Deslauriers et al. (2012) conducted a study on temperature and swimming speed in juvenile shortnose sturgeon, acipenser brevirostrum. Sopinka et al. (2013) revealed that using a fixed‐speed test, burst swimming performance was found to vary among nine populations of emergent sockeye salmon Oncorhynchus nerka fry reared in a common garden environment. And, they revealed that no consistent relationship was, however, detected between difficulty of fry migration to rearing areas and total burst swimming duration or bursting rate.

Many studies have been conducted to change the flow in the fishway and create an environment where fish can easily go up. Wada (1990) conducted experiments on various partition shapes in the fishway and found that the slope-type run-up rate was the highest. Furthermore, it was clarified that the climbing rate was the highest when the slope angle was 60 °. Onitsuka et al. (2015, 2018) examined how the installation of various wooden partitions in the pool and weir in the fishway changed the behavior of the fish. In addition, they observed the swimming behavior of Zacco platypus when the arrangement of the boulders was changed in a stream with gravel on the riverbed. Aoki et al. (2018) changed the conditions for setting the gravel in the fishway pool, and changed the flow structure in the river channel by placing a flat plate on the gravel to understand the flow structure and conducted a fish behavior experiment. Although many studies on fishways have been conducted indoors and outdoors, few experiments have clarified the effects of different shapes on fishways existing in rivers.

The purpose of this study is to understand the hydraulic characteristics of a stepped fishway using two existing fishways. In examining the fishway of the actual river, the manager provided information on the shape of the fishway, but there was a request not to specify which fishway was used. For this reason, this paper will proceed with the analysis as Fishway A and Fishway B.
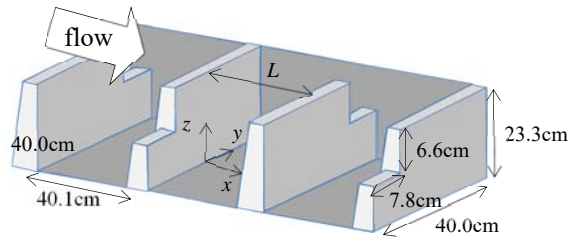
(a) Fishway A
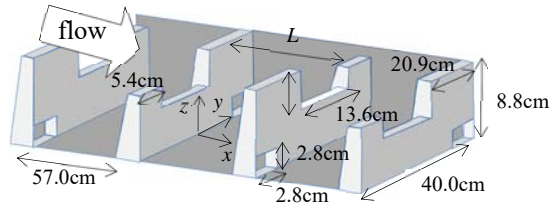
(b) Fishway B

Figure 1. Fishway model used for hydraulic experiments

Table 1. Experimental Conditions

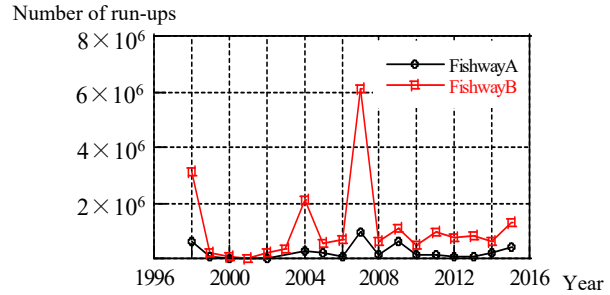| Case	Flow discharge Q (l/s)	Bed slope I	Downstream length of pool L (cm)	Model scale
Fishway A	6	1/40	40	1/2.6
Fishway B			56	1/7.4

Figure 2. Ayu (sweetfish) run-up number per year

2. APPARATUS AND EXPERIMENTAL METHOD

In this study, a model of the existing stairway type Fishway A and Fishway B shown in Figure 1 is prepared and installed in an open channel in a room. The Fishway B has a latent hole at the bottom of the partition wall. The experiment in this study was conducted by using a recirculating slope varying acrylic-resin flume measuring 10 m in length, 40 cm in width and 25 cm in height. Plywood was used as the material for the model. Table 1 shows the experimental conditions. Plywood was used as the model material, and the scale was adjusted to the actual size of the fishway according to the width of the open channel, with Fishway A being 1 / 2.6 and Fishway B being 1 / 7.4. Due to this scale, the installation intervals of the models in the downflow direction were 40 cm for Fishway A and 56 cm for Fishway B, and 9 models and 8 pools were arranged. The model was arranged so that the notches alternated in the downflow direction.

The origin of the coordinate system is located at the upstream end of the cavity in the measurement zone and at the center of the bottom of the flume. The coordinate system, which is a right-hand system, has its x-axis in the stream flow direction, y-axis in the cross-channel direction and z-axis in the vertical direction. Their flow velocity components are represented by u, v and w; their means, U, V and W; and their variation components, u', v' and w'.

For the measurement of flow velocity, point measurement of flow velocity using electromagnetic current meter and simultaneous measurement of flow velocity using PIV (particle image velocimetry) method were performed. In each case, the range of the velocity measurement was the fifth pool from the upstream where the flow in the pool is considered to be stable. Output signals at 100 Hz from the electromagnetic flow meters were converted from analog to digital, and a total of 4,096 data sets per measurement point were processed statistically. The cross sections of the flow velocity measurement were three points: an upstream point in the pool where $x = 2$ cm, a midstream point which is half the length of the pool in the downstream direction, and a downstream point 2 cm upstream from the downstream end of the pool for both Fishways A and B. In the PIV, an air-cooled visualization source (output 2W) was used as a light source. Laser light sheet thickness and pulse interval were set at 2 mm and 2 ms, respectively, and the laser beam was irradiated from the right bank of the flume toward the left bank. The measurement interval time was 25 Hz, the comparison screen interval time was 125 Hz, and the measurement time was 60s. Nylon particles having a diameter of 63~150μm and a specific gravity of 1.01 were used as tracers. The measurement position was 0.2, 0.5, and 0.8 times the horizontal plane at the depth H for each fishway. Fishway A is $H = 22$cm and Fishway B is $H = 9$cm.

3. NUMBER OF RUN-UPS IN ACTUAL RIVERS IN EACH FISHWAY

Figure 2 shows the number of ayu fish (sweetfish) running up in each fishway. Here, Fishway A is 4 km upstream from Fishway B. The run-up number of sweetfish changes every year, and the change is similar in both fishways. However, the number of Fishway B was large in all years, especially in 2007, Fishway B showed 6.4 times the number of Fishway A. Thus, in addition to the problem of the location of the fishway, it is necessary to consider the relationship between the fishway structure and the number of run-ups.
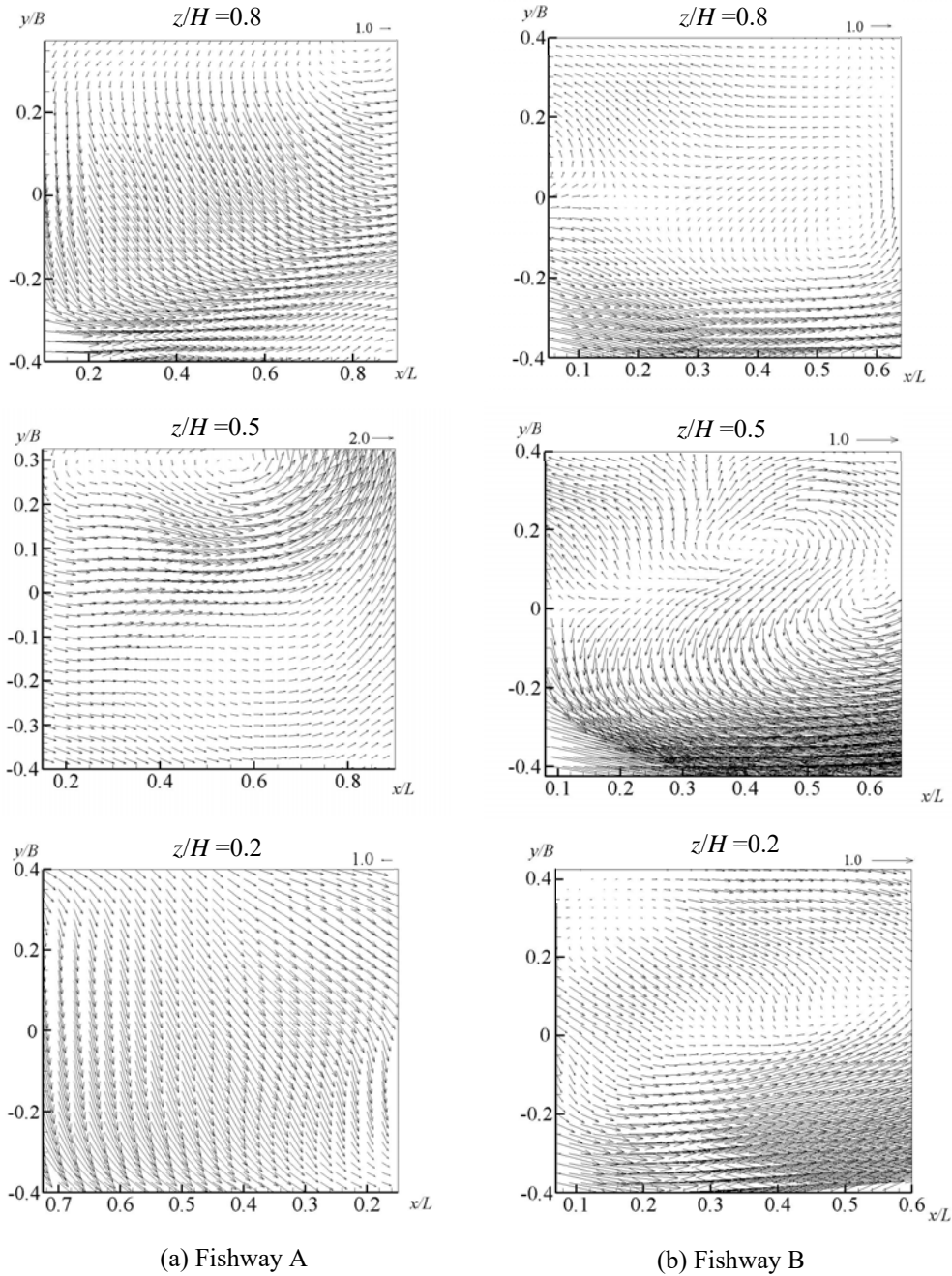
(a) Fishway A　　　　　　　　　(b) Fishway B

Figure 3. Velocity vector distribution in horizontal plane

4. VELOCITY VECTOR DISTRIBUTION IN HORIZONTAL PLANE

Figure 3 shows the velocity vector on the horizontal plane in each fishway. The measurement positions are z/H = 0.2, 0.5, 0.8, and the velocity vector is dimensionless with the average cross-sectional velocity.

Focusing on Fishway A, the flow velocity shows a large value on the right bank side at z/H = 0.8 due to the effect of water flowing out from the notch. At z/H = 0.5, it can be seen that a circulating flow is occurring on the left bank side of the pool. In addition, the flow shows the direction toward the notch downstream, and the flow velocity shows a large value, and the flow velocity becomes small on the right bank side.

In Fishway A, it is considered that there is a space on the right bank side where fish can rest. At z/H = 0.2, the circulation flow cannot be confirmed, but it can be seen that the flow velocity around the notch shows a large value.

Focusing on z/H = 0.5 in Fishway B, two circulating flows are observed downstream of the left bank, and the velocity vector shows a large value on the right bank. This is thought to be due to the presence of the submerged hole downstream of the right bank, causing strong flow in that direction. Although this tendency can be seen at z/H = 0.8, it can be confirmed that the flow velocity on the left bank shows a smaller value than the flow velocity on the right bank with a notch on the downstream side. At z/H = 0.2, it can be seen that the flow velocity shows a large value on the right bank side with the dive.
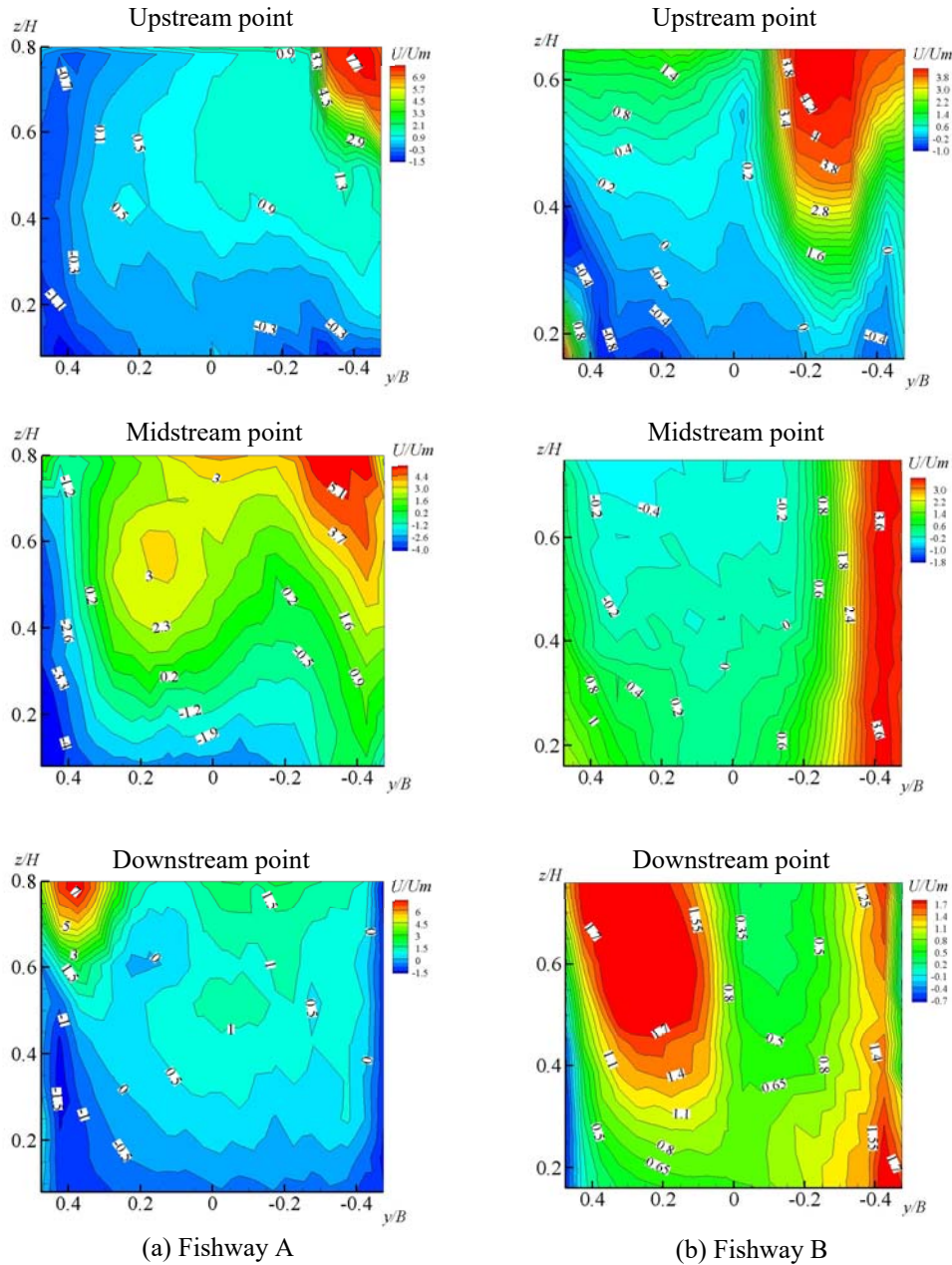
Figure 4. Main flow velocity U/U_m contours in cross section

From these figures, it can be confirmed that a more complicated flow field occurs on the horizontal plane in Fishway B than in Fishway A, and it is recognized that there is no clear resting place for fish going up.

5. VELOCITY VECTOR DISTRIBUTION IN CROSS SECTION

5.1 Main flow velocity contours in cross section

Figure 4 shows the contour lines of the main velocities in the cross section of Fishways A and B. The upstream point is located 2 cm downstream from the pool upstream, where x/L=0.05 for Fishway A and x/L=0.04 for Fishway B. Both of the midstream points have x/L=0.50. The downstream point is a cross section of 2 cm upstream from the downstream end of the pool, where Fishway A has x/L=0.95 and Fishway B has x/L=0.96. Both main velocities are dimensionless with the average cross-sectional velocity.

Focusing on Fishway A, the main flow velocity shows a large value on the right bank near the water surface, which is a position having a notch on the upstream side at the upstream point. Even at the middle stream point, the main flow velocity shows a maximum value on the right bank near the water surface, but it can be seen that the flow velocity also increases near the center of the channel. At the downstream point, the main flow velocity shows the maximum value on the left bank side near the water surface, which is near the position having the notch on the downstream side. In each case, the main flow velocity is small near the bottom, which is considered to be a rest space for fishes.

Next, focusing on Fishway B, it can be confirmed that the flow velocity shows a maximum value at the upstream point at the position having the cutout portion at the upstream, and the flow velocity shows a large value also at the dive part. At

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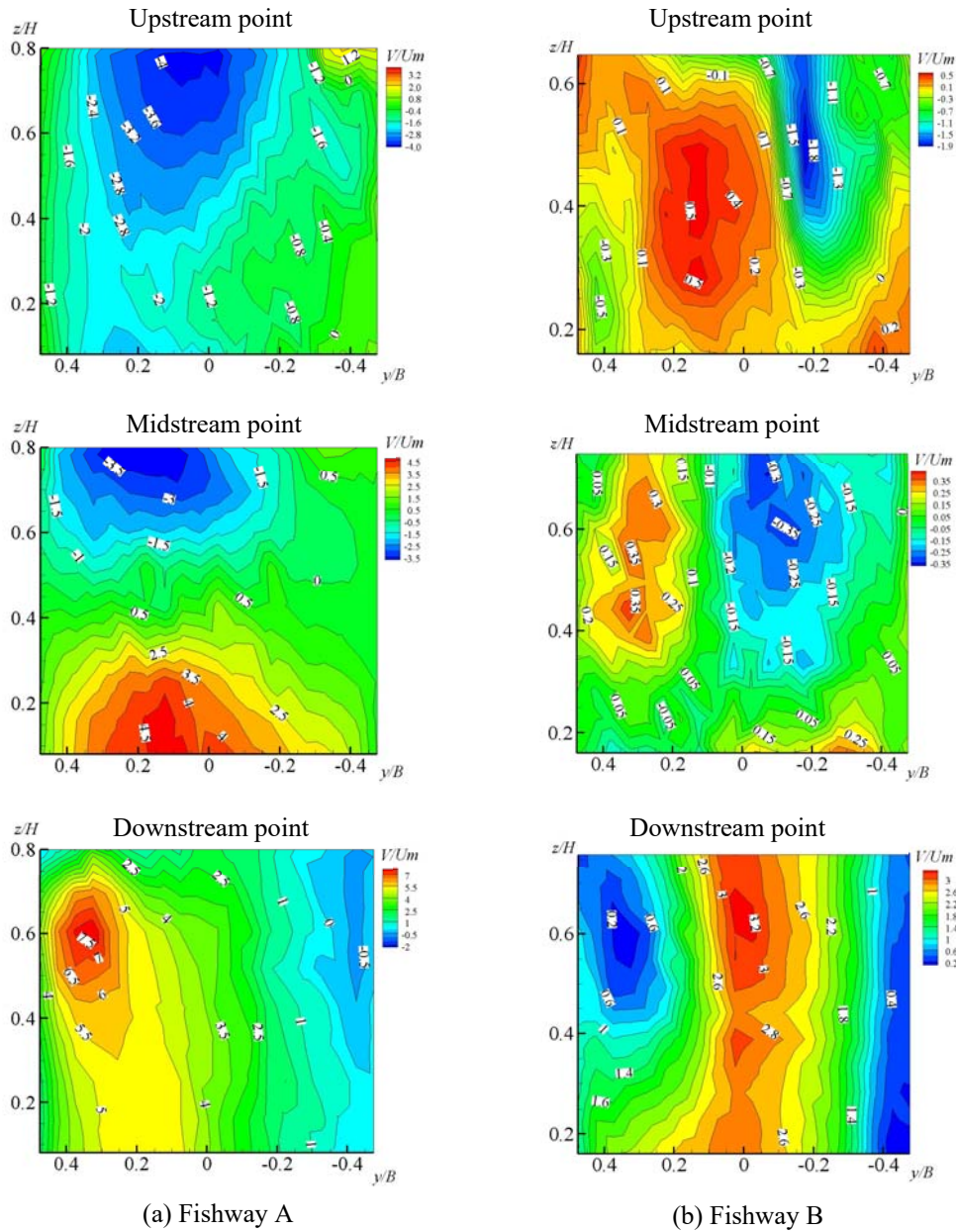
Figure 5. Transverse velocity V/U_m contours in cross section

the midstream point, the main flow velocity shows a large value in the vertical direction uniformly on the right bank side, and the influence of the upstream diving port is small and the effect of the downstream diving port appears strongly. At the downstream point, the main flow velocity shows the maximum value on the left bank above $z/H = 0.3$ due to the effect of the notch on the downstream side. In addition, it can be seen that the influence of the submerged mouth is on the right bank side, and the effect of the upstream notch remains near the water depth. In addition, compared with the Fishway A, it was clarified that there was no clear space for the fish to take a break because the sections where the flow velocity was small were different in each section.

5.2 Transverse velocity contours in cross section

Figure 5 shows the contour lines of the transverse velocities in the cross section of Fishways A and B. Focusing on Fishway A, it can be seen that the stream is facing the right bank direction at an upstream point from a half depth to a high point around the center of the channel. This is thought to be due to the effect of water flowing from the upstream right bank hitting the partition wall on the downstream right bank and generating a circulating flow, as can be seen from the horizontal velocity vector. At the midstream point, the distribution is similar to that at the upstream point at a depth of more than half the water depth, and at $z/H = 0.4$ or less, the flow toward the left bank can be confirmed. This is thought to be due to the flow toward the notch on the left bank on the downstream end. At the downstream point, the flow toward the left bank appears strongly on the left bank side, and the flow toward the notch is formed.

In the Fishway B, at the upstream and downstream points, a flow toward the right bank is formed at a position more than half a water depth on the right bank side from the center of the channel, and a flow toward the left bank is formed at the left bank side. This is thought to be due to the clear separation into the flow toward the lower hole on the lower right bank side and the flow toward the notch on the upper left bank side. In each cross
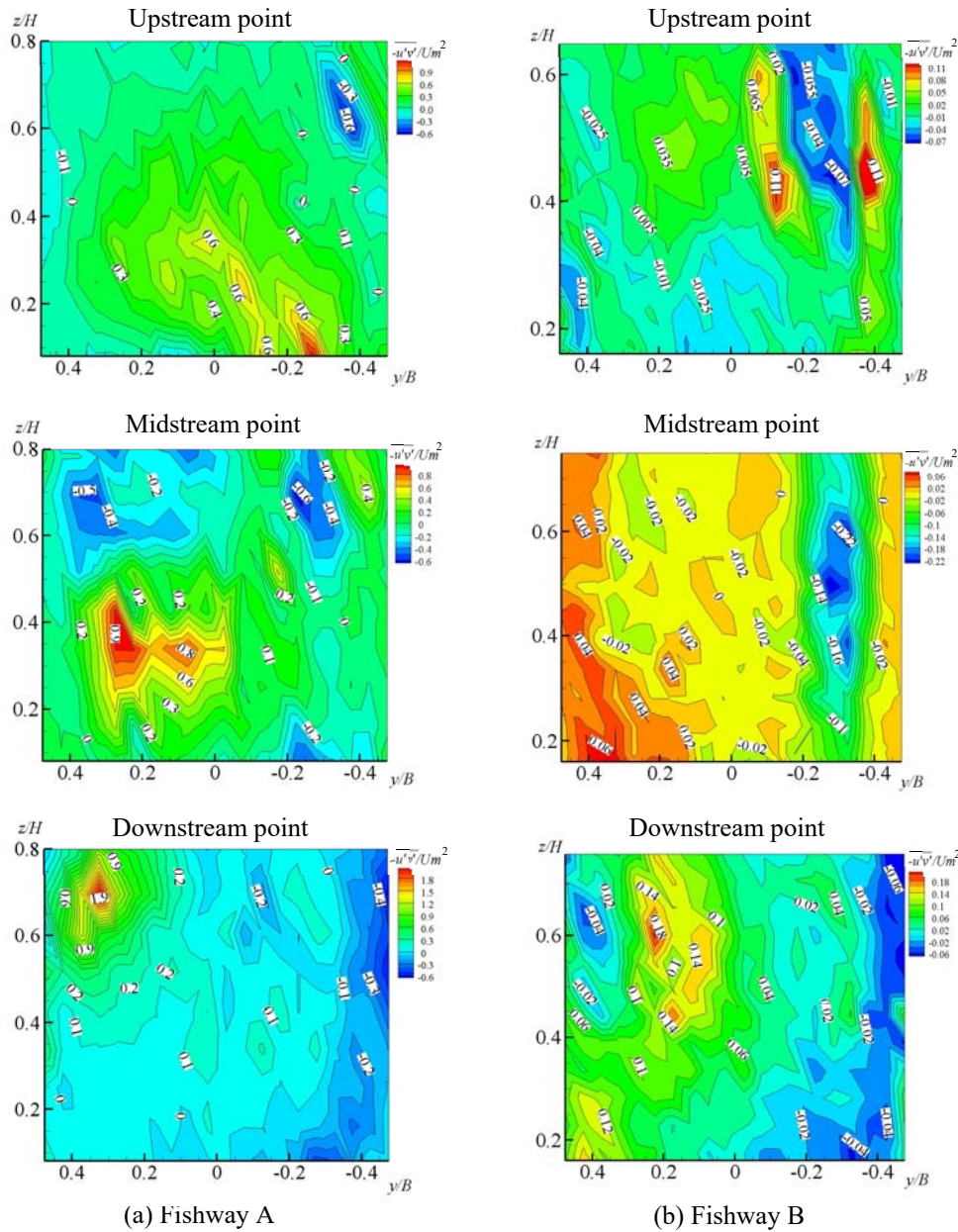
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Figure 6. Transverse Reynolds stress $-\overline{u'v'}/U_m{}^2$ distribution in cross section

section, a flow toward the left bank occurs on the right bank side from the center of the channel due to the influence of the submerged mouth near the bottom surface. At the downstream point, the flow toward the left bank in the vertical direction appears strongly at the position having the notch. Also, at the position with the dive, the flow toward the right bank can be seen. In particular, in Fishway B, it was confirmed that the flow was directed in different directions in the transverse direction.

6. TRANSVERSE REYNOLDS STRESS DISTRIBUTION IN CROSS SECTION

Figure 6 shows the transverse Reynolds stress distribution in cross section of Fishways A and B. In each case, the dimension is reduced to the square of the cross-sectional average flow velocity.

In the Fishway A, at the position having the notch on the upstream side, the Reynolds stress shows a negative extreme value, and it can be seen that the momentum is carried to the left bank. At the midstream point, large turbulence occurred on the left bank side at a position higher than the half-water depth, indicating the effect of the notch on the upstream and downstream. In addition, the Reynolds stress shows a positive extreme value below the half water depth on the left bank side from the center of the channel, and it can be confirmed that the three-dimensionality of the flow is strong. At the downstream point, a positive extreme value is obtained at a position having a notch on the downstream side. However, at other positions, the disturbance was small and it was recognized that it was suitable as a fish resting place.

In the Fishway B, the Reynolds stress has positive and negative extreme values around the notch at the upstream point. This is thought to be the effect of the notch not being installed along the side wall. In addition, the Reynolds stress also has a negative extreme value at the position where the submerged opening is installed. At

the midstream point, it can be confirmed that the right bank shows negative values in the vertical direction due to the effects of the notch on the upstream side and the submergence on the downstream side. In addition, near the bottom surface on the left bank side, it shows a positive extreme value. At the downstream point, the Reynolds stress shows extreme positive and negative values at a height of more than half water depth on the left bank side with a notch downstream. In addition, the right bank shows a negative extreme value in the vertical direction, and the influence of the submarine opening appears near the bottom.

From the above results, it became clear that the flow showed a three-dimensional behavior in Fishway A, especially in the center of the pool, compared to Fishway B.

7. CONCLUSIONS

In this study, the difference of the flow structure between two different fishways was examined. As a result, it was found that a complicated flow occurred especially in the horizontal plane in the fishway with a structure with a submerged hole, and there was no clear place to rest for the fish going up. It was confirmed that 56% of swimming fish use burrows in Japan[1], and it is necessary to consider their installation sufficiently. In addition, due to the flow velocity distribution in the cross section, Fishway A showed a stronger three-dimensionality of the flow than Fishway B, especially at the center of the pool. Furthermore, it became clear that the distribution tendency of the turbulent structure differs greatly depending on the installation position of the notch. As a result, it became clear that it was important to carefully consider not only the presence or absence of a submerged opening but also the location of the notch.

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