THE FLOW CHARACTERISTICS AROUND THE SPUR DIKES AND SWIMMING BEHABIOR OF FISH TO IT

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ABSTRACT

This study focused on the environmental functions of flood control structures. Especially, we focused on the spur dikes in this study. The spur dikes are a traditional river construction method in Japan. The purposes of this study were clarified the fish behavior regarding the flow around the spur dikes by difference in longitudinal interval. The experiments were to observe the behavior of real fish, to measure the flow velocity and the water depth. The columns were changed longitudinal interval and arrangement. The real fish used in the experiments are *Tribolodon hakonensis*. The average body length of the fish is 8.6(cm) (6.7 to 10.2(cm)). The water temperature during the experiments was 18.3 to 24.5(℃). The results are show below. 1) There was a tendency for the fish to use the immediately downstream of the column for a long time. Because the flow velocity immediately downstream of the column was the flow velocity that fish can swim for a long time. 2) The time for the fish to swim in the group of columns was 10 times longer in case the interval between the column was wide. Because the area of flow velocity that fish can swim for a long time has expanded. The flow velocity downstream group of columns is 70(%) degree less than that upstream of group of columns. Therefore, it is appeared that the flood control function of the group of columns used in this study has been secured.

Keywords: spur dike, flood control structures, river environmental, fish behavior, *Tribolodon hakonensis*

1. INTRODUCTION

Japanese river improvement is changing with the times. The latest revision of the River Law (1997) added the improvement of river environments as its main purpose. In 2006, the basic policy of creating a natural river was announced. This is the basis of all river making. In this way, river improvement focusing on the river environment is being performed. In this study, focused on the fish behavior.

The fish behavior is greatly affected by the presence or absence of river structures in the river. There are many structures which are groin and etc. for flood control. A groin has a flow velocity reduction function and a splash function. Therefore, it is used in various situations. Among them, spur dikes have been used as a traditional river method since ancient times. Because, the spur dikes are simple and easy to construct. Research on the spur dikes (group of columns) has been carried out through model experiments and numerical analysis. Akikusa et al. (1960) clarified the basic functions of water control. In recent years, it is expected that aquatic organisms (mainly fish) may use the area where the flow velocity is reduced as a habitat. Takamizu et al. (2007) or Aoki et al. (2009) performed experiments and numerical analysis, and showed that spur dikes could be used as a shelter or rest area for fish. Onitsuka et al. (2016) performed experiments by treating the column as vegetation and changing the vegetation density. As the results, it was confirmed that *Zacco platypus* (Oikawa) uses the vegetation area as a rest area. Sakama and Aoki (2017) performed experiments with varying permeability. As the results, it was shown that the dwarf *Tribolodon hakonensis* (Ugui) stayed near the groin. Fukudome et al. (2010) installed a groin on a straightened channel of a mountain river, restoring the composition of the near-natural pool.

As has been noted, groin is attracting attention because those are used as fish habitats, shelters and rest areas in addition to the original flood control functions. However, it has not been clarified how fish use spur dikes (group of columns). The purposes of this study were to clarify the use situation of fish in the spur dikes. The experiments were to observe the behavior of real fish, to measure the flow velocity and the water depth.

2. EXPERIMENTAL METHODS

Figure 1 shows a schematic diagram of the experimental channel. The experimental channel used was a single-section open channel with a width of 80(cm) and a length of 1,080(cm). An observation section of 300(cm) was set up upstream. Table 1 shows the experimental cases. A column with a height of 15(cm) and a diameter of 4.8(cm) was used for the pseudo spur dikes. These were installed on the right bank in the observation section as a zigzag arrangement and an aligned arrangement (Figure 2). The swimming speed of fish is expressed by body length speed to standardize differences in fish species and size. There are three main types of fish swimming speed: the cruising speed, the intermediate speed, and the blast speed. The cruising speed is the swimming speed that can be maintained for a long time. Specifically, it is the speed of 2 to 4 times the body length ($\overline{BL}$) per second. The blast speed is a swimming speed that can be exerted instantaneously. Specifically, it is the speed of 10 times the body length ($\overline{BL}$) per second. The intermediate speed indicates the swimming speed between them. In this study, the average flow velocity of section u_m without the columns was changed to $4\overline{BL}$(cm/s) (the cruising speed) and $6\overline{BL}$(cm/s) (the intermediate speed). This assumes normal times and floods.

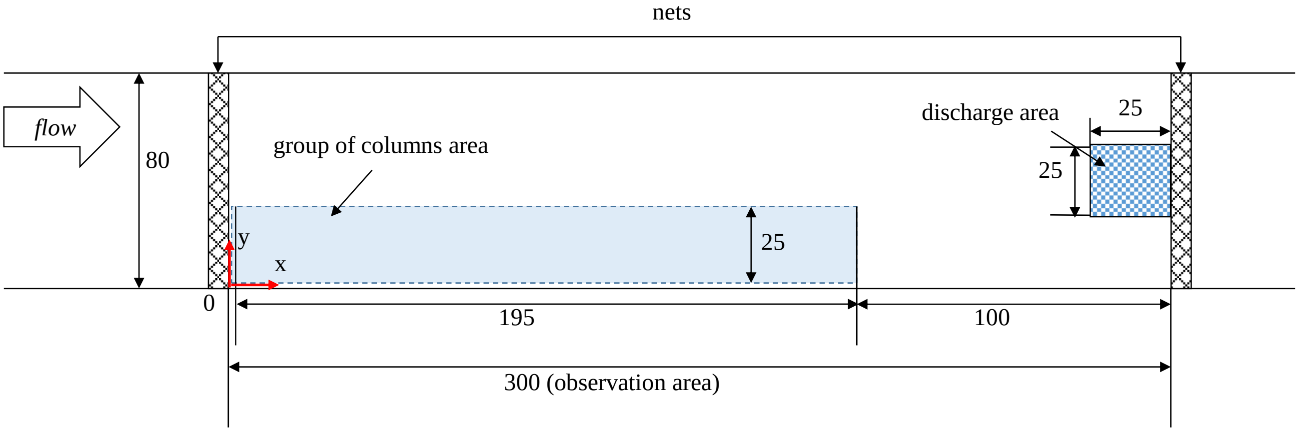
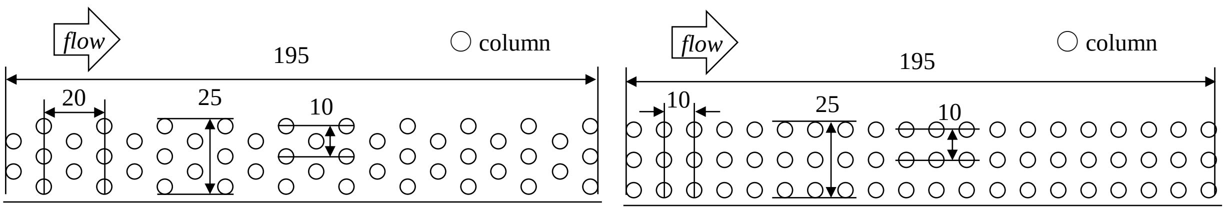


Figure 1. The experimental channel (unit:(cm))

Table 1. Cases considered in the experiments.

Case	arrangement of the columns	flow rate	average flow velocity of section	average length of the fish	water depth
1-0	-	30(l/s)	approximately $4\overline{BL}$(cm/s)	8.3(cm)	12(cm)
1-1	zigzag				
1-2	aligned				
2-0	-		approximately $6\overline{BL}$(cm/s)	7.5(cm)	8.5(cm)
2-1	zigzag				
2-2	aligned				



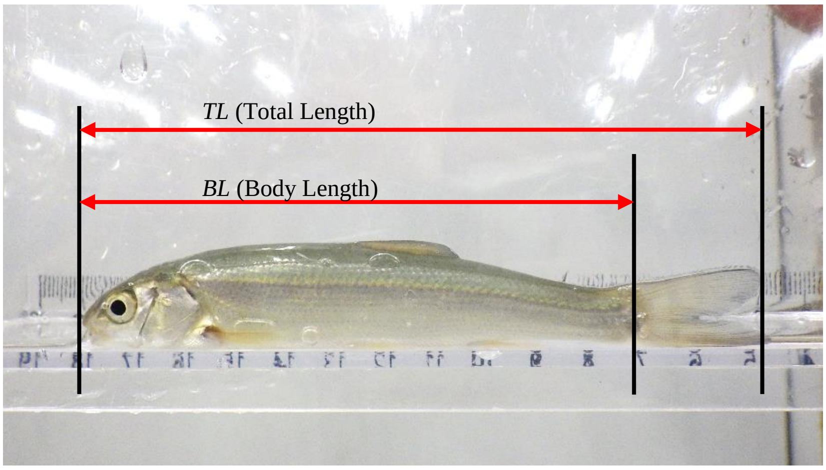
a) Zigzag arrangement   b) Aligned arrangement

Figure 2. Arrangement of the group of columns

2.1 Experiments of real fish behavior

Tribolodon hakonensis (Ugui) inhabiting all over Japan was used as a real fish (Picture 1). The length of the fish used in this experiment is BL=6.4 to 10.4(cm) (average length $\overline{BL}$=8.3(cm)) in Case1, and BL=6.2 to 8.2(cm) (average length $\overline{BL}$=7.5(cm)) in Case2. When the length of the fish exceeds 4.0(cm), it swims with the same flow velocity as the adult fish. Therefore, the average length ($\overline{BL}$) differs depending on the case, but there is no difference in basic swimming characteristics.

In the experiments, the fish was released to the downstream of the observation section and allowed to adjust to swimming water for 5(min). After that, the fish behavior was observed and captured with a video camera for 30(min). Ten fish were used in one experiment, and three experiments were performed in each case. In addition, different individuals were used for each experiment in consideration of the learning ability of fish. The water temperature during the experiment was 18 to 23(℃) and the illuminance on the water surface was approximately 400(lx).



Picture 1. *Tribolodon hakonensis* (Ugui)

2.2 Hydraulic experiments

Figure 3 shows a schematic diagram of the measurement points. At each measurement point, the flow velocity and water depth were measured. A two-dimensional electromagnetic current meter (KENEK, VM2001) was used to measure the flow velocity. The sampling frequency was set to 20(Hz), and the 512 data measured at each measurement point were simply averaged. The flow velocity was measured at 2.0(cm) (z=2.0(cm)) above the bed. Because, the swimming depth of the fish was approximately 2.0(cm) above the bed. Digital point gauge (KENEK, PH-102) was used for water depth measurement.

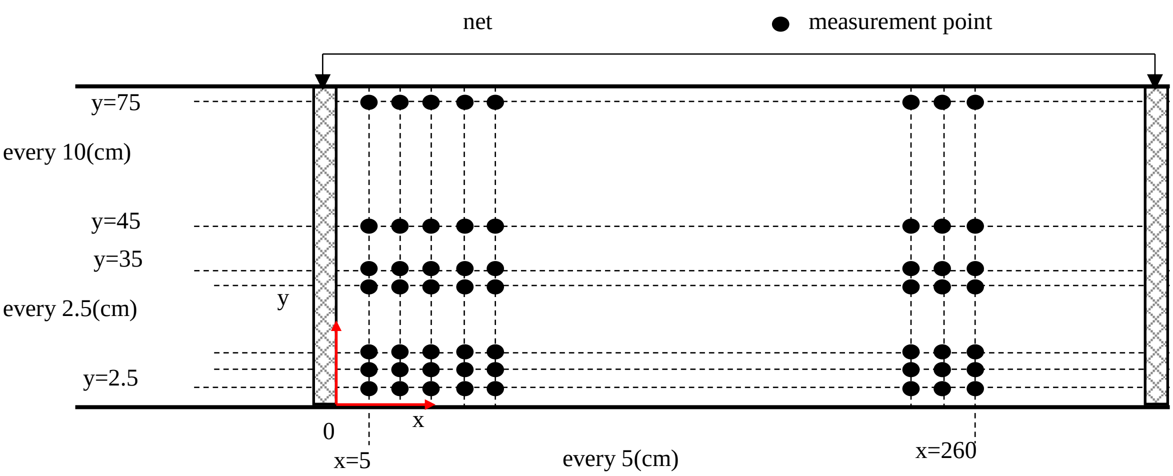


Figure 3. Measurement points

3. RESULTS OF EXPERIMENTS

3.1 The real fish behavior immediately after the start of the experiments

Focused on the movement of the fish for 1 minute after the start of the experiment (Figure 4). The fish swam up the center of the channel and the left bank. After that, they entered the group of columns. There were also some fish that continued to swim near the discharge area.

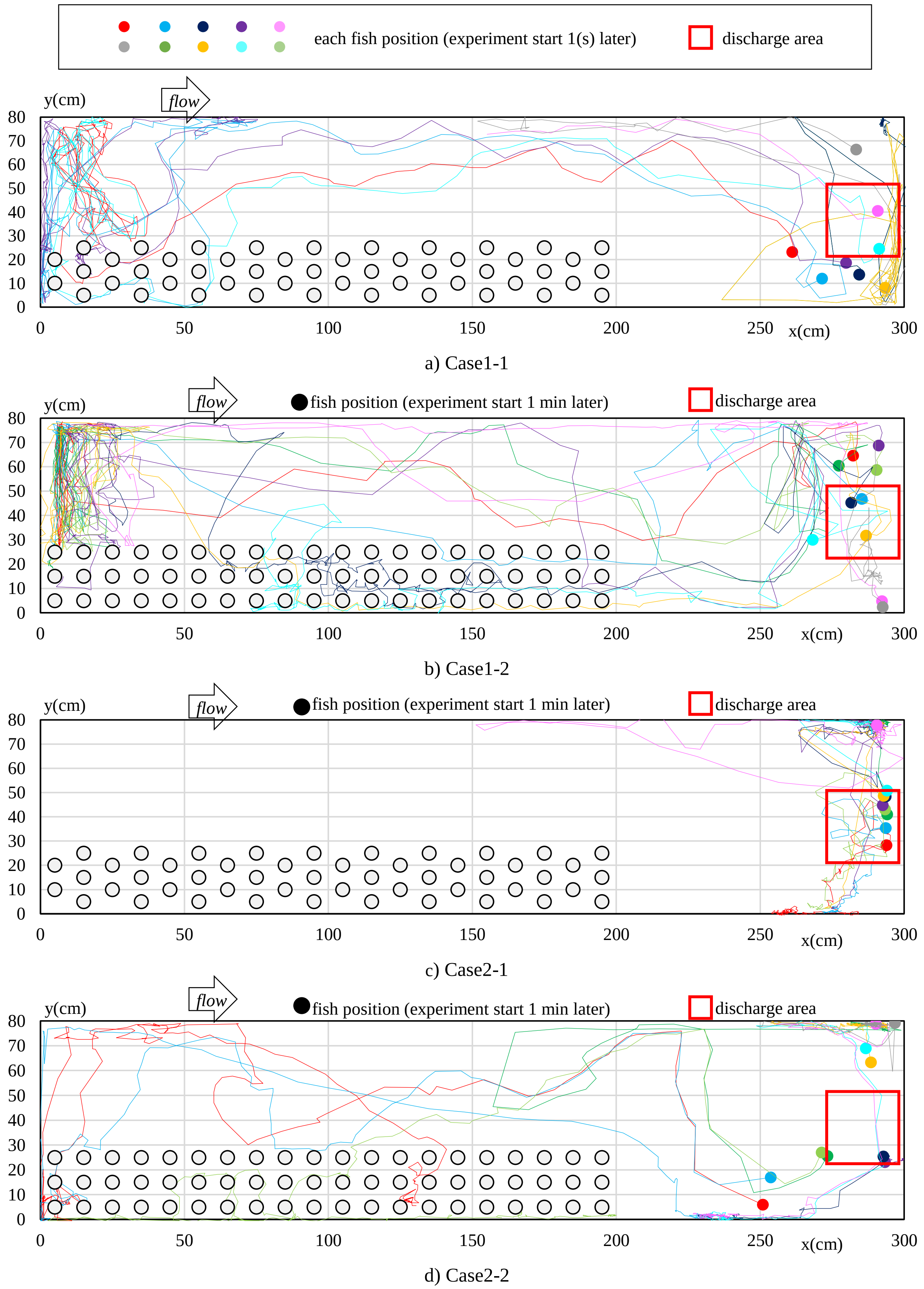


Figure 4. Swimming route of the fish 1 to 60(s) after the start of the experiments

3.2 The real fish behavior that entered the group of columns

Figure 5 shows the number of times the fish has entered the group of columns. The state where the fish's head is located at 0≤x(cm)<200 and 0≤y(cm)<30 is defined as "entered". In Case1-1 and 1-2, the fish entered the group of columns more than 50 times from the upstream of the group of columns (0≤x(cm)<50). In Case2-1 and 2-2, the fish entered the group of columns less than 15 times from the upstream of the group of columns (0≤x(cm)<50). Therefore, focused on the flow around the group of columns. The $\overline{u}\,\overline{v}$ vector diagram and the composite flow velocity $\overline{V}$ contour diagram are shown (Figure 6). In each case, a splash occurred upstream of the group of columns. Its flow direction is toward the center of the channel. Thus, it is probable that Case 1-1 and 1-2 sensed splashed flow and entered the group of columns. However, in Case2-1 and 2-2, almost no the fish entered from the upstream of the group of columns. Therefore, focused on the flow velocity near the group of columns (y=35(cm)). Figure 7 shows the change diagram of the combined flow velocity $\overline{V}$ in the longitudinal direction. The flow velocity by the group of columns was approximately $4\overline{BL}$(cm/s) (the cruising speed) in Case1-1 and 1-2, and 6 to $10\overline{BL}$(cm/s) (the intermediate speed) in Case2-1 and 2-2. Thus, in Cases 2-1 and 2-2, it was difficult for the fish to run up and it was not easy to enter from the upstream of the group of columns.

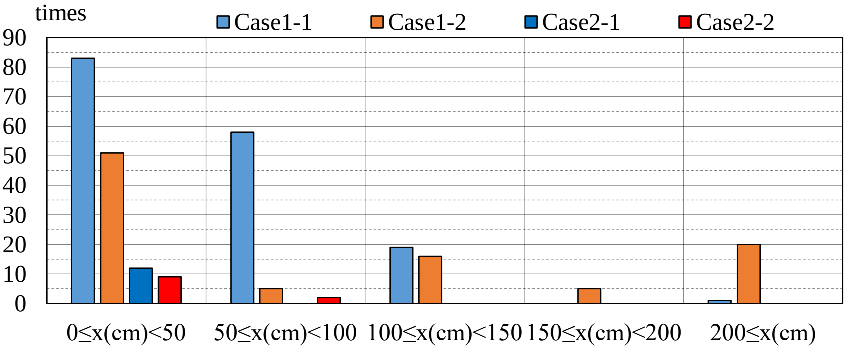


Figure 5. The total number of times the fish has entered the group of columns

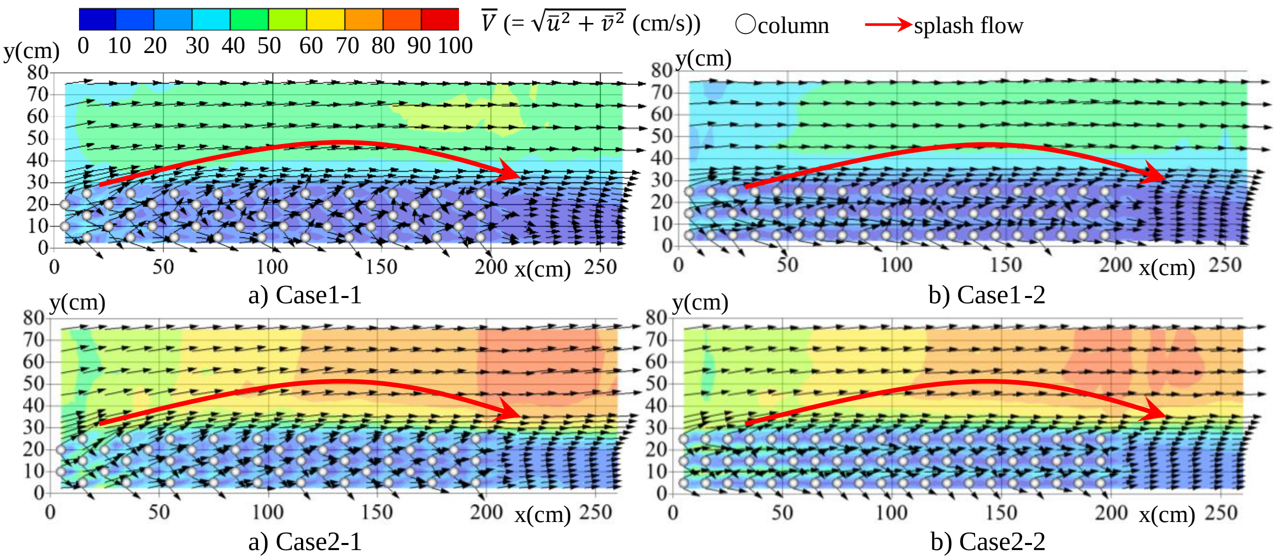


Figure 6. $\overline{u}\,\overline{v}$ vector diagram and composite flow velocity $\overline{V}$ contour diagram

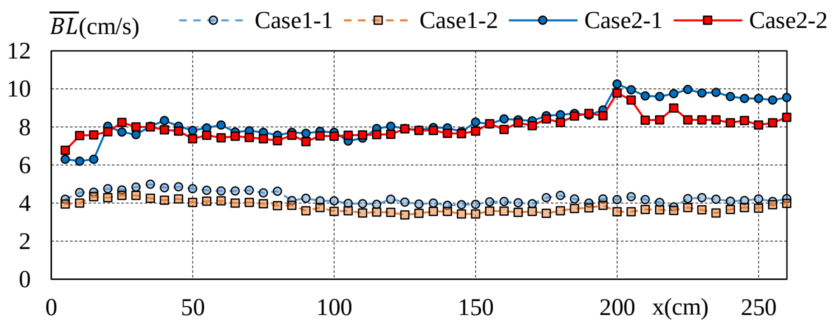


Figure 7. Longitudinal change of the composite flow velocity $\overline{V}$ by the group of columns (y=35(cm), z=2(cm))

3.3 Using the group of columns of the fish

Figure 8 shows an average time of the fish using the group of columns. Also, the situation of the fish swimming in the area (y=0 to 30(cm)) more than 5 seconds is defined as “used”. In Case1-1, after the fish entered the group of columns, the fish was swimming over there and using the group of columns. Also, in the group of columns, the fish was using a downstream of the group of columns (Figure 9). Therefore, focused on the flow velocity of longitudinal direction in the group of columns. Figure 10 shows a change of the composite velocity of longitudinal direction in the group of columns. In Case1-1, the flow velocity in the group of columns is no more than $4\overline{BL}$(cm/s), and there are many places the flow velocity is no more than $2\overline{BL}$(cm/s) like an immediately downstream of the group of columns. Thus, after entered the group of columns, the fish hardly changed its swimming position. In Case1-2, after the fish entered the group of columns, it gradually moved downstream between the columns in the longitudinal direction (Figure 9). Ultimately, the fish used the area where is downstream of the group of columns (200≤x(cm), y(cm)<30). The flow velocity in the group of columns was more than $4\overline{BL}$(cm/s) (the cruising speed) at 0≤x(cm)<50, and less than $4\overline{BL}$(cm/s) at 50≤y(cm) (Figure10). Thus, it is probable that the fish moved downstream in the group of columns. On the other hand, the reason may be that the space used by the fish downstream of the columns was narrow. In Case2-1, after the fish entered the group of columns, it stayed 1 to 2(s) downstream of the columns (Figure 9). After that, it moved as to be swept downstream of the group of columns. As in Case1-1, the flow velocity downstream of the column was less than $2\overline{BL}$(cm/s). However, the flow velocity between the columns was more than $4\overline{BL}$(cm/s) at 0≤x(cm)<40 and $4\overline{BL}$(cm/s) at 40≤x(cm) (Figure 10). Thus, it is probable that the fish moved downstream in the group of columns. In Case2-2, immediately after enter the group of columns, the fish moved so as to be swept away between the columns without staying there. This is because the flow velocity between the columns was 4 to $8\overline{BL}$(cm/s), and it was difficult for the flow velocity to stay in that place (Figure 10).

In addition, there were the fish using the downstream area of the group of columns (200≤x(cm), y(cm)<30) in all cases. The fish used while moving in the downstream area of the group of columns with head of the fish facing upstream (Figure 11). This was the same in all cases. This was because the flow velocity in the downstream area of the groupof columns was less than $3\overline{BL}$(cm/s) (Figure 10), and the flow velocity was high enough for the presence of the fish.

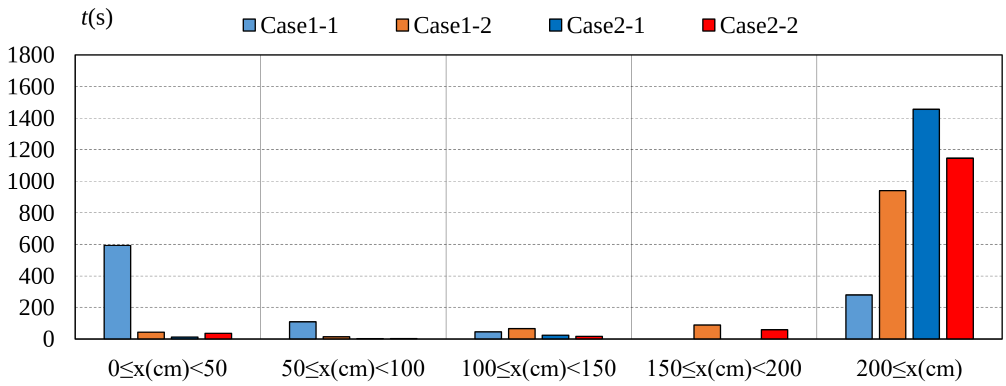
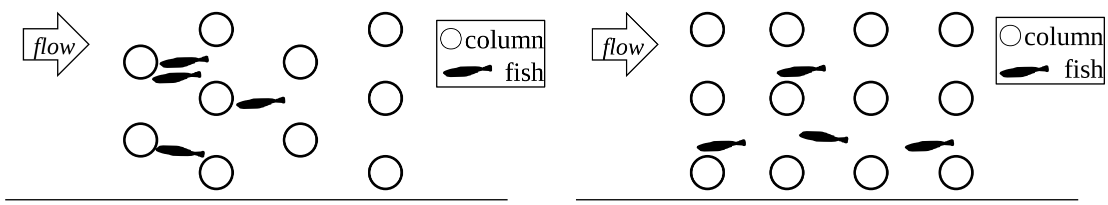


Figure 8. The average time the fish used the group of columns



a) downstream of the columns b) between the columns

Figure 9. The main used area of the fish in the group of columns

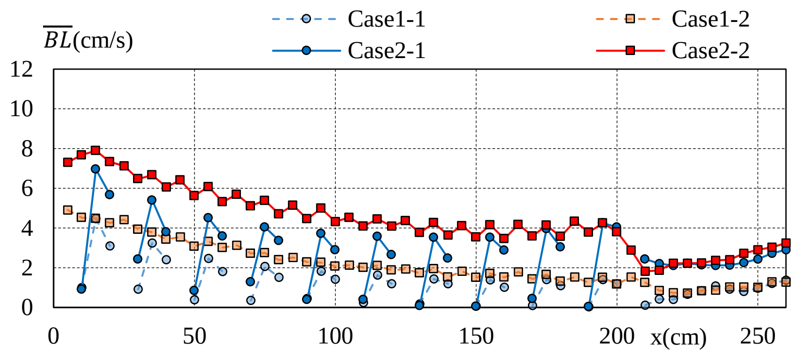


Figure 10. Longitudinal change of the composite flow velocity $\overline{V}$ in the group of columns

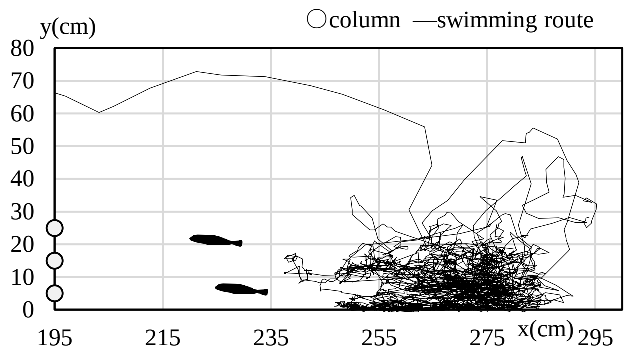


Figure 11. Examples of swimming route of the fish in the downstream area of the group of columns

4. CONCLUSIONS

The findings obtained in this study are as follows.

1. In the zigzag arrangement, the flow velocity downstream of the column was less than $2\overline{BL}$(cm/s) (the cruising speed), which was used by the fish. On the other hand, the fish gradually moved downstream in the aligned group. It is also possible that the fish could not use the area downstream of the column due to the narrow spacing between the columns in the longitudinal direction.
2. In all cases, the fish using the downstream area of the group of columns (200≤x(cm), y(cm)<30) was confirmed. The flow velocity in this area was less than $3\overline{BL}$(cm/s) in all cases. This was a flow velocity at which the fish was likely to exist.

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