# EFFECTS OF BOULDERS INTERVAL IN STREAMWISE DIRECTION OVER OPEN CHANNEL BED ON SWIMMING BEHAVIOR OF ZACCO *PLATYPUS*

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It is important to keep suitable area by boulders to make rest area for fish. This study was conducted to research the relations between swimming behavior of *Zacco platypus* and boulders interval in streamwise direction over open channel bed. Swimming behavior of *Zacco platypus* was obtained with the aid of two sets of digital video cameras. It was found that swimming of *Zacco platypus* was stagnant remarkably in case where the boulders interval in downstream direction is narrow. It is because that there are more low velocity spaces in this case compared with case where the boulders interval in downstream direction is wide.

## 1 INTRODUCTION

Keeping the migration rate of fish high is important when a fishway is designed. A pool-and-weir fishway is majority in Japan. In pool-and-weir fishway, factors affecting the migration rate of fish are drop level of water, partition wall shape and roughness [1]. It is recommended that the drop of pool is 0.15m or less [2]. Wada [3] measured the number of migrated fish by changing the shape end of partition wall to rectangle, slope and circle. As a result, slope and circle of the shape caused the increasing number of migrated fish. In Aki-gawa River, it was confirmed that boulders has affected kind and number of the migrated fish [4] [5]. The boulders at bottom over pool bed in pool-and weir fishway caused the increasing number of migrated fish [6]. Fusamae [7] also indicated this result in a laboratory experiment. The large size boulders at bottom of pool caused the decreasing time for migration of fish [8] [9]. Miyazono & Tomatsu [10] found that *Salvelinus leucomaenis leucomaenis* gets through around boulder for migration. Onitsuka *et al*. [11] found that *Zacco platypus* swims between boulders over pool bed in pool-and-weir fishway. On the other hand, Aoki *et al*. [12] found that gravel hinders migrating of *Tribolodon hakonensis*. In this way, it is not cleared that whether a roughness have a good influence for migration of fish or not. Therefore, it is necessary to research of the boulders effect for fish's swimming behavior in simple flow condition. It is assumed that relations of the boulders interval and the body length of fish are important. In this study, swimming behavior of *Zacco platypus* in open channel were compared with change of boulders interval in streamwise direction over open channel bed.

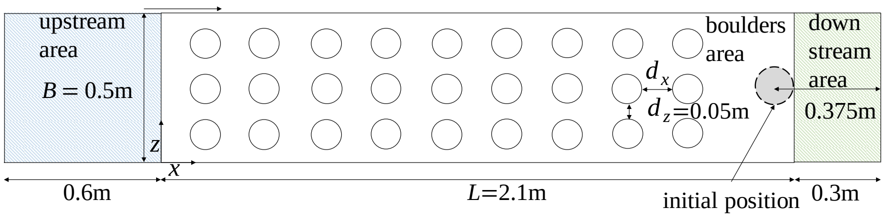



Figure 1. Open-channel

Table 1. Experimental cases

| case | boulders diameter $D$ (m) | boulders interval (m) | |
|---|---|---|---|
| | | $x$ direction $d_x$ | $z$ direction $d_z$ |
| 1 | 0.1 | 0.1 | 0.05 |
| 2 | | 0.2 | |
| 3 | | 0.3 | |
| 4 | | 0.4 | |

Figure 2. Fish used for this experiment

## 2 EXPERIMENTAL DEVICE AND METHODS

Figure 1. shows the open-channel. Pool length was 2.1m, width ($B$) was 0.5m and height was 0.25m. Directions of $x$, $y$ and $z$ were the coordinate of the streamwise, the vertical and the spanwise directions, respectively. Boulders were placed on the range ($L$=2.1m) from upstream edge of the open-channel in the $x$ direction. The boulders diameter ($D$) was 0.1m. The area placed boulders was named as boulders area. The areas that were located in upstream and downstream of boulders area were named as upstream area and downstream area. Table 1. shows experimental cases. The boulders interval in $z$ direction ($d_z$) was 0.05m, and the boulders interval in $x$ direction ($d_x$) was set to 4 patterns (0.1, 0.2, 0.3 and 0.4m). Flow velocity divided by averaged body length of fish was set to 7 (1/s) in the upstream area. The number of boulders placed on the open-channel bed were 27, 18, 15 and 12 in case 1 to 4. Water depth ($h$) was 0.2m and, the boulders were completely underwater. Figure 2. shows *Zacco platypus* used for this experiment. The number of used fish was 1 in one recording. The recording has been carried out for 10 conditions in each case and 40 conditions in total. This experiment was conducted with 40 fish. Averaged body length ($\overline{B_L}$) of fish was about 70mm. A circular wire net of 0.15m in diameter was set up 0.375m upstream from downstream edge, and the fish was inserted. After the fish was settled down, the circular wire net was taken up. Further, trajectory of fish was recorded with two digital video cameras set up the upside and the right side of open-channel for 90 seconds. The number of fish reached in upstream area and swimming position were analyzed after recording. Further, the flow velocity ($V_V$) was measured using 3D electromagnetic velocity meter.

## 3 RESULTS AND DISCUSSION

### 3.1 Hydraulic properties of open-channel

Figure 3. shows flow velocity ($V_V$) on each height ($y$=0.125, 0.075, 0.025m) of open-channel for cases 1 to 4 ($d_x$=0.1, 0.2, 0.3 and 0.4m). Figure 3 (c) shows that there were the low velocity area at upstream and downstream of boulders at the height ($y$= 0.025m) in case 1 ($d_x$=0.10m). In cases 2 to 4 ($d_x$=0.20, 0.30, 0.40m), there were the low velocity area at upstream and downstream nearby the boulders. Besides, there were more fast flow between the boulders than upstream and downstream nearby the boulders. Figure 3 (a), (b) show that the flow velocity is faster at the height ($y$= 0.075, 0.125m) than that at the height ($y$= 0.025m).

### 3.2 Passage rate of fish

Passage rate was defined as following equation.

$$\text{Passage rate} = \frac{\text{Number of fish that arrived at upstream area } n_p}{\text{Number of fish that used to experiment } N} \tag{1}$$

Figure 4 shows the correlation between the boulders interval in $x$ direction ($d_x$) and the passage rate of fish ($n_p / N$). As the boulders interval in $x$ direction ($d_x$) has increased, the passage rate of fish ($n_p / N$) decreased. Therefore, it was assumed that passage rate of fish ($n_p / N$) is low when the boulders interval in $x$ direction ($d_x$) is wide.

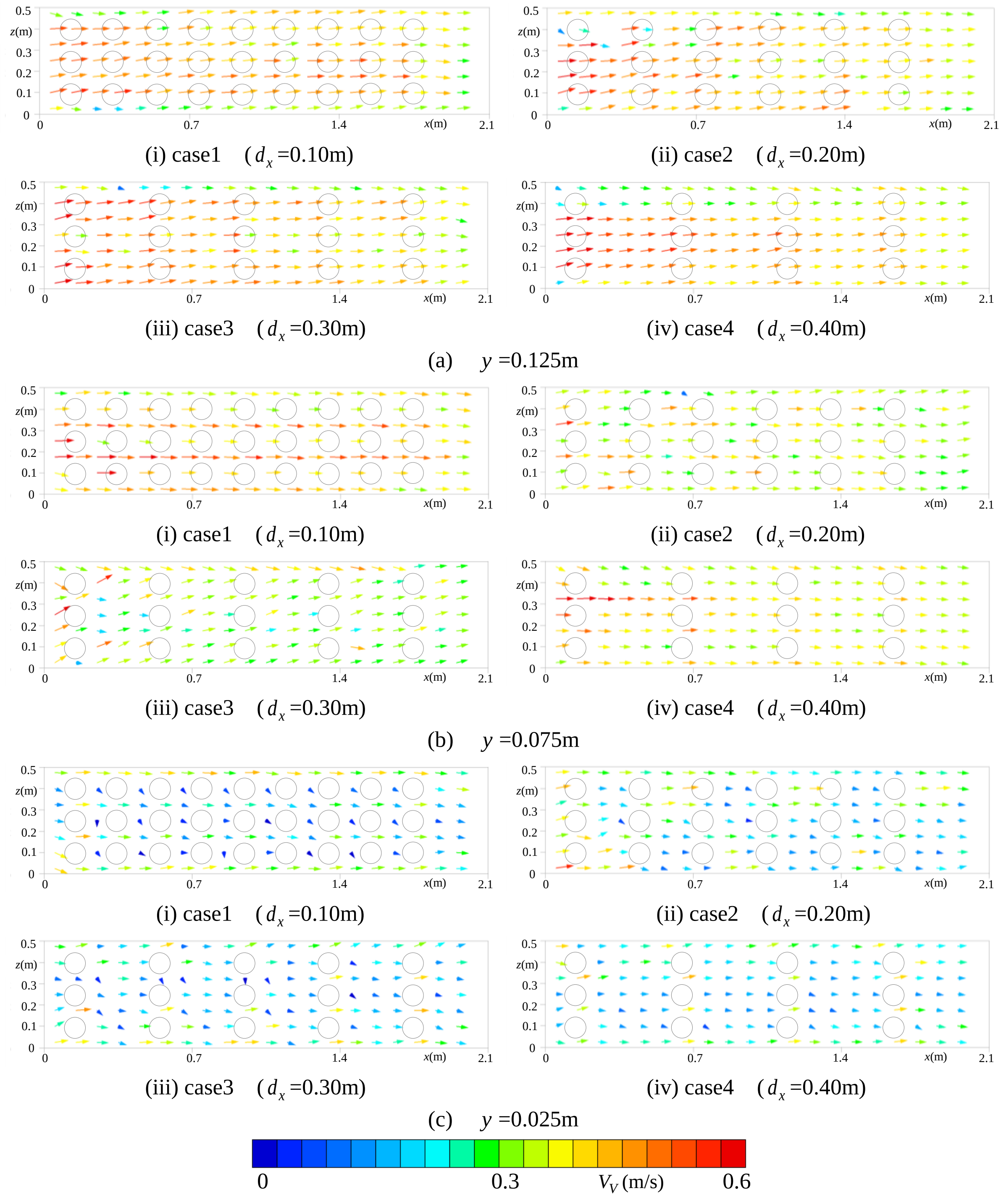



Figure 3. Flow velocity ($V_V$) on each height ($y$ = 0.125, 0.075, 0.025m) of open-channel

### 3.3 Swimming frequency of fish in *y* direction

The average number of fish on the time per swimming position in $y$ direction ($\overline{n_y}$) was calculated based on the number of fish per swimming position in $y$ direction ($n_y$). Figure 5. shows swimming frequency of fish in $y$ direction ($\overline{n_y}/N$). In all cases ($d_x$=0.1, 0.2, 0.3, 0.4m), many fish swam at the level under top of boulders ($0 \le y/h \le 0.5$). In cases 3, 4 ($d_x$=0.3, 0.4m), swimming position of fish was higher than that in cases 1, 2 ($d_x$=0.1, 0.2m).

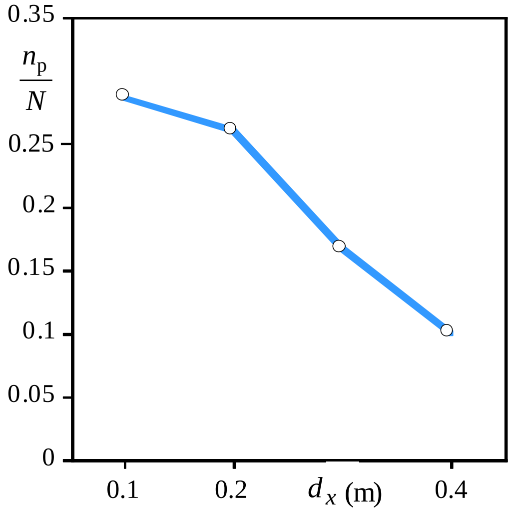



Figure 4. Passage rate of fish

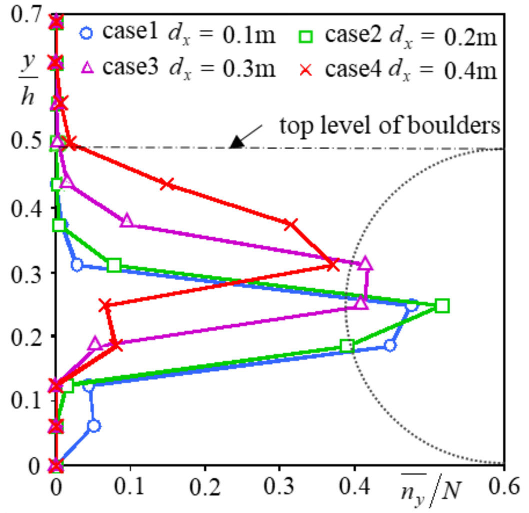
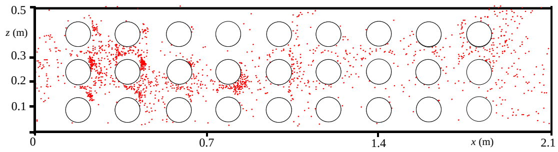
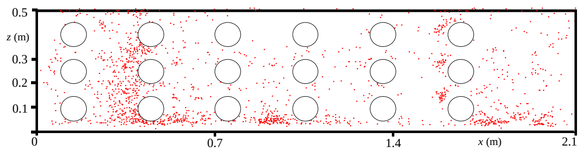


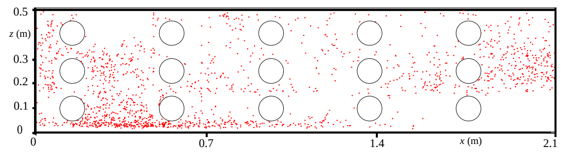

Figure 5. Swimming position in $y$ direction



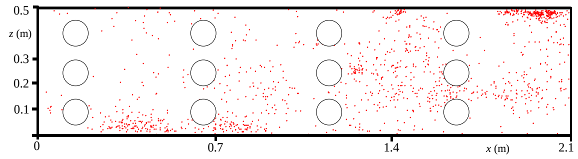
(a) case1 ($d_x$ =0.1m)



(b) case2 ($d_x$ =0.2m)



(c) case3 ($d_x$ =0.3m)



(d) case4 ($d_x$ =0.4m)

Figure 6. Swimming position of fish in *x-z* direction

### 3.4 Swimming position of fish in *x-z* direction

Figure 6. shows swimming position of fish in *x-z* direction per 0.5 seconds in 90 seconds. In case 1 ($d_x$ =0.1m), many fish swam behind the boulders. In case 2 ($d_x$ =0.2m), fish swam in upstream and downstream of the boulders. In case 3 ($d_x$ =0.3m), more fish swam near the side wall of open-channel than case 1 ($d_x$ =0.1m) and case 2 ($d_x$ =0.2m). In case 4 ($d_x$ =0.4m), the most fish swam near the side wall in all cases. Therefore, it was indicated that increasing of the boulders interval in $x$ direction ($d_x$) reduce the distance between fish and boulders.

### 3.5 Distance between fish and the side wall divided by averaged body length of one

The average number of fish on the time per swimming position in $z$ direction ($\overline{n_z}$) was calculated based on the number of fish per swimming position in $z$ direction ($n_z$). Figure 7. shows relations between swimming position of fish in $z$ direction ($z/\overline{B_L}$) and swimming frequency of fish in $z$ direction ($\overline{n_z}/N$). As the boulders interval in $x$ direction ($d_x$) has increased, swimming frequency around the center of open-channel ($2.0 \le z/\overline{B_L} \le 4.0$) decreased. Besides, swimming frequency nearby the side wall of open-channel ($0 \le z/\overline{B_L} < 2.0$) increased. Figure 3 shows that when the boulders interval in $x$ direction ($d_x$) has increased, the low velocity area nearby boulders decreased. Thus, many fish swam in low velocity area nearby the side wall of open-channel.

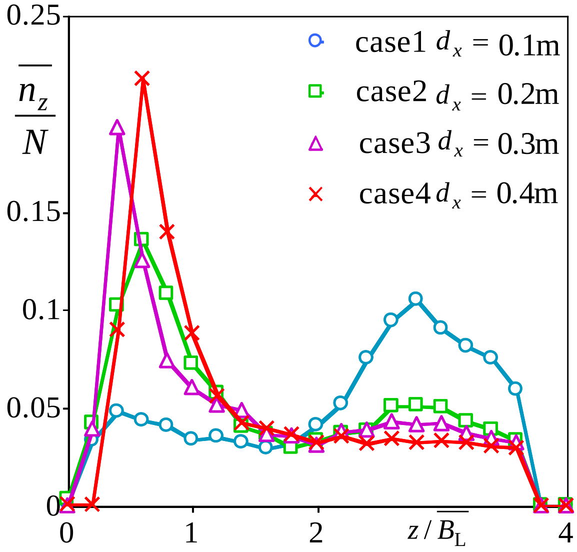



Figure 7. Distance between fish and the side wall divided by averaged body length of one

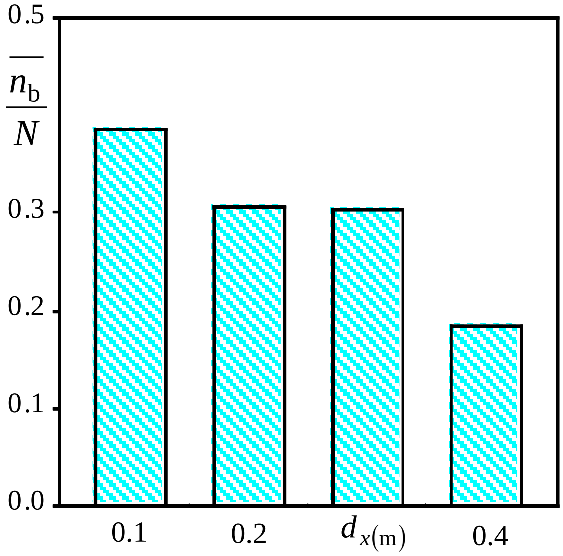



Figure 8. Fish's utilization ratio of boulders

### 3.6 Fish's utilization ratio of boulders

The number of fish swimming in boulders interval ( $n_b$ ) was counted, and the average number of fish ( $\overline{n_b}$ ) was calculated. Furthermore, fish's utilization ratio of boulders ( $\overline{n_b}/N$ ) was calculated. Figure 8. shows relations between the boulders interval in $x$ direction ( $d_x$ ) and fish's utilization ratio of boulders ( $\overline{n_b}/N$ ). Fish's utilization ratio of boulders ( $\overline{n_b}/N$ ) was the highest in case 1 ( $d_x$ =0.1m). As the boulders interval in $x$ direction ( $d_x$ ) has increased, fish's utilization ratio of boulders ( $\overline{n_b}/N$ ) declined. Consequently, fish's utilization ratio of boulders ( $\overline{n_b}/N$ ) was the lowest in case 4 ( $d_x$ =0.4m). Figure 3 shows that there were more fast flow between the boulders than upstream and downstream nearby the boulders in case 4 ( $d_x$ =0.4m). Thus, decrease of the low velocity area nearby boulders disturbed using this area of fish in case 4 ( $d_x$ =0.4m).

### 3.7 Stagnation rate of fish's swimming

Stagnation was defined as swimming distance of the fish in 0.5s was 0.1 times or less of averaged body length ( $\overline{B_L}$ ) of the fish. The number of stagnation ( $n_s$ ) was counted, and the average number of fish ( $\overline{n_s}$ ) was calculated. Figure 9. shows relations between the boulders interval in $x$ direction ( $d_x$ ) and stagnation rate ( $\overline{n_s}/N$ ).Figure 8. shows that as the boulders interval in $x$ direction ( $d_x$ ) has increased, fish's utilization ratio of boulders ( $\overline{n_b}/N$ ) declined. Thus, stagnation rate has decreased.

### 3.8 Fish angle in horizontal surface

Fish angle ( $|\theta|$ ) was defined as absolute value of the angle by two lines (the line linked the tail to the head and the line of $x$ axis). The upstream direction ( $|\theta|$ ) was 0°, and the downstream direction ( $|\theta|$ ) was 180°. The number of fish per fish angle ( $n_\theta$ ) was counted, and the average number of fish ( $\overline{n_\theta}$ ) was calculated. Figure 10. shows frequency of fish angle ( $\overline{n_\theta}/N$ ) in all cases ( $d_x$ =0.1, 0.2, 0.3, 0.4m). The frequency of fish angle ( $\overline{n_\theta}/N$ ) was high frequency at low value of fish angle ( $|\theta|$ ) in cases 1, 2 ( $d_x$ =0.1, 0.2m). On the other hand, the frequency of fish angle ( $\overline{n_\theta}/N$ ) was lower at low value of fish angle ( $|\theta|$ ) than in cases 1, 2 ( $d_x$ =0.1, 0.2m). Besides, in cases 3, 4 ( $d_x$ =0.3, 0.4m), the frequency of fish angle ( $\overline{n_\theta}/N$ ) was higher at high value of fish angle ( $|\theta|$ ) than in cases 1, 2 ( $d_x$ =0.1, 0.2m). Therefore, it was indicated that many fish face downstream when the boulders interval is large. In cases 1, 2 ( $d_x$ =0.1, 0.2m), fish's utilization ratio of boulders ( $\overline{n_b}/N$ ) and stagnant rate ( $\overline{n_s}/N$ ) was high than in cases 3, 4 ( $d_x$ =0.3, 0.4m). Besides, in cases 1, 2 ( $d_x$ =0.1, 0.2m), there were the

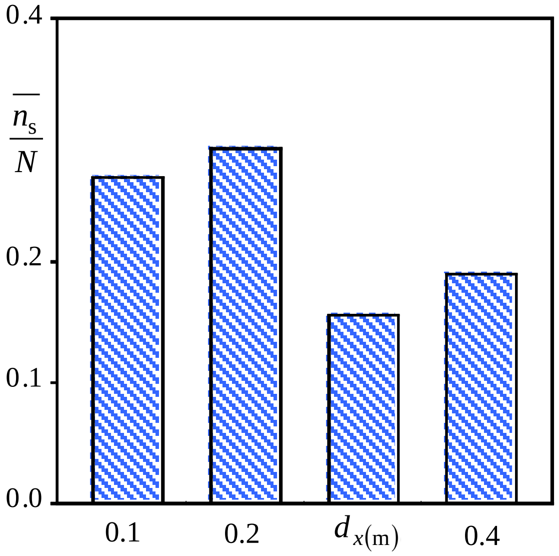



Figure 9. Stagnant rate of fish

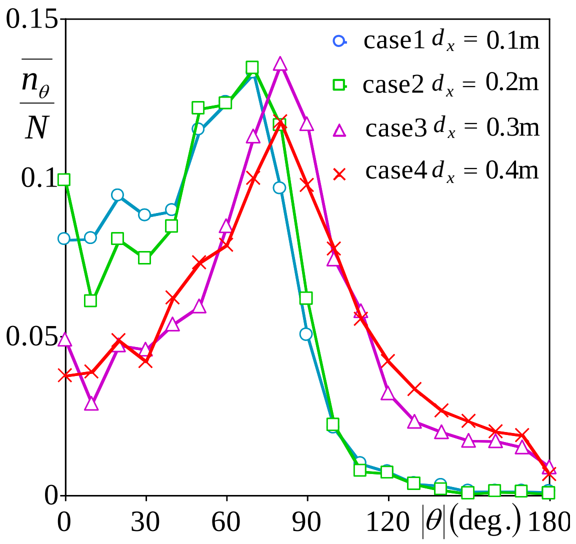



Figure 10. Fish angle in horizontal surface

more low velocity area nearby boulders than in cases 3, 4 ($d_x$=0.3, 0.4m). Fish has a positive rheotropism. Thus, the fish faced upstream and rested at nearby boulders. On the other hand, in cases 3, 4 ($d_x$=0.3, 0.4m), the rest frequency was low, and the more fish swam in the high velocity area. Thus, in cases 3, 4 ($d_x$=0.3, 0.4m), the more fish was flowed to downstream than in cases 1, 2 ($d_x$=0.1, 0.2m). Therefore, it was indicated that in cases 3, 4 ($d_x$=0.3, 0.4m), the more fish faced downstream than in cases 1, 2 ($d_x$=0.1, 0.2m).

## 4 CONCLUSION

This study was conducted to research the relations between swimming behavior of *Zacco platypus* and boulders interval in streamwise direction over open channel bed. As a result, it was found following.
Increasing of the boulders interval in streamwise direction causes declining of the fish's utilization ratio of boulders, and fish swims nearby side wall. Besides, in a case same as this, there are more fast flow between the boulders than upstream and downstream nearby the boulders. Thus, decrease of the low velocity area nearby boulders disturbs using this area of fish.

## 5 ACKNOWLEDGEMNETS

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