Effects of instillation locations of boulders at bottom of pool-and-weir fishway on migration rate of Zacco platypus

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EFFECTS OF BOULDERS LOCATIONS OVER POOL BED IN POOL-AND-WEIR FISHWAY ON MIGRATION RATE OF *ZACCO PLATYPUS*

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ABSTRACT

It is important to keep suitable area by boulders in pool-and-weir fishway to make the migration rate of fish high. In this study, migrating behaviors of *Zacco platypus* in pool-and-weir fishway were compared with locations of boulders placed on the bottom of pool-and-weir fishway changed. Migration behaviors of *Zacco platypus* were obtained with the aid of two digital video cameras. It was found that *Zacco platypus* migrates remarkably uses the space between boulders when boulders were placed on the upper bottom in the pool. It is because the velocity of space between boulders is low compared to other space.

INTRODUCTION

Dam is constructed for the purpose of water control and water utilization. However, dam blocks fish's migration that seeks to upstream. This is a problem for migratory fishes in river. Therefore, fishway is constructed in their rivers in order to comfort migration of fishes. Nakamura (1995) has reported that the most of fishway in Japan is pool-and-weir fishway. Pool-and-weir fishway has notch at the weir wall. Width of notch is generally twenty or thirty percent of the weir wall's one. In calm river, over flow arise from only notch, so there is high velocity flow at point of fall. Sanz-Ronda *et al*. (2015) have shown that fish's swimming speed is roughly classified into two types: sustained speed and burst speed. The latter causes fatigue. In case of migration at pool-and-weir fishway, fish sometimes uses burst speed. Therefore, it is necessary to keep resting area in the pool (see Nakamura, 1995). One of the method is an establishment of boulders. In Aki-gawa River, it was confirmed that boulders has affected kind and number of the migrated fish (see Kaneko *et al*., 1997, Takasaki *et al*., 1999). It was confirmed that the large size boulders at bottom of pool decreases the time for migrating (see Santos *et al*., 2013, Santos *et al*., 2014). Miyazono & Tomatsu (2003) found that *Salvelinus leucomaenis leucomaenis* goes through around boulder for migration. Onitsuka *et al*. (2016) found that *Zacco platypus* swims between boulders. Aoki *et al*. (2015) found that decrease of the cross sectional flow area hinders migration of *Tribolodon hakonensis*.

It is necessary to investigate boulder's effect on migrating behaviors of *Zacco platypus* in the pool. Besides, making suitable area in easy way is important. In this study, migrating behaviors of *Zacco platypus* in pool-and-weir fishway were compared with the locations of boulders placed on the bottom of pool-and-weir fishway changed.

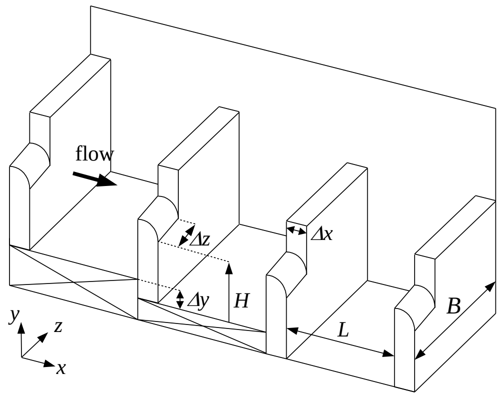


Figure 1, Pool-and-weir fishway

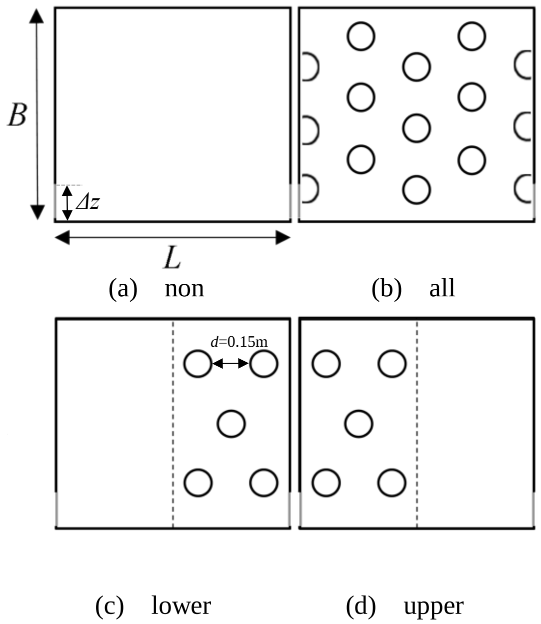


Figure 2, Boulders location over pool bed

Table 1. Experimental case

boulders area \ Q(l/s)	1	3	5
non	noQ1	noQ3	noQ5
all	alQ1	alQ3	alQ5
lower	loQ1	loQ3	loQ5
upper	upQ1	upQ3	upQ5

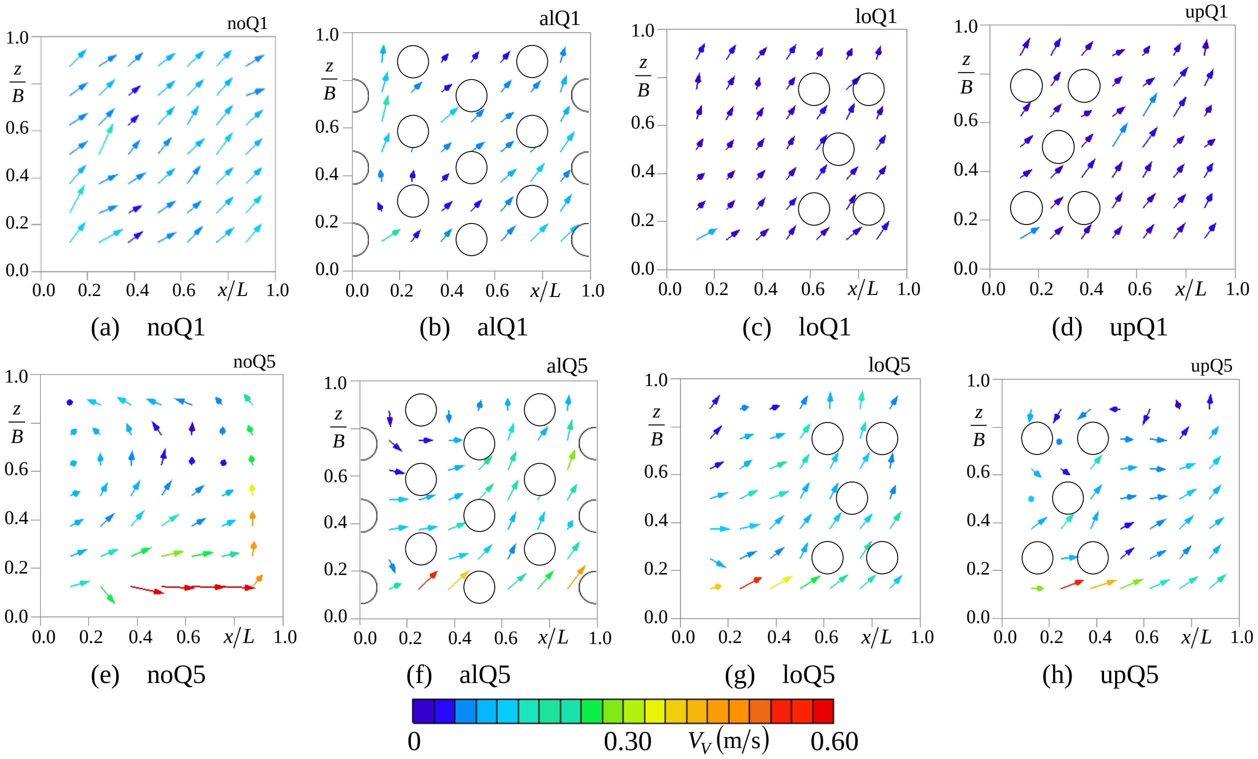


Figure 3. Flow velocity (V_V) at the bottom of second pool in pool-and-weir fishway

EXPERIMENTAL SETUP AND CONDITION

Figure 1 shows pool-and-weir fishway. It is designed following. Pool length (*L*) is 0.9m and width (*B*) is 0.8m. The pool is connected in a staircase pattern. Thickness of the partition wall (Δx) is 0.2m, pool drop (Δy) is 0.15m and notch width (Δz) is 0.16m. Height from the pool bottom to a notch bottom (*H*) is 0.3m. Pool number is in ascending order toward upstream. Figure. 2 shows location of boulders which is inserted in second pool. In this study, the shape of boulder is a spherical (see Miyazono *et al*, 2005). 20 *Zacco platypus* average length B_L =70mm are put into the second pool. The locations of boulders are 4 patterns. Table. 1 shows experimental cases. Discharge (*Q*) is set to 3 patterns within the range from 1 to 5(l/s). Experiments are performed 12 cases in total. After it is confirmed that the isolated *Zacco platypus* settled down, recording is began with the video camera from the left side wall and the upper part of this fishway for 30 minutes. The number of migration and swimming position, was analyzed after recording. Further, the flow velocity V_V was measured using 3D electromagnetic velocity meter.

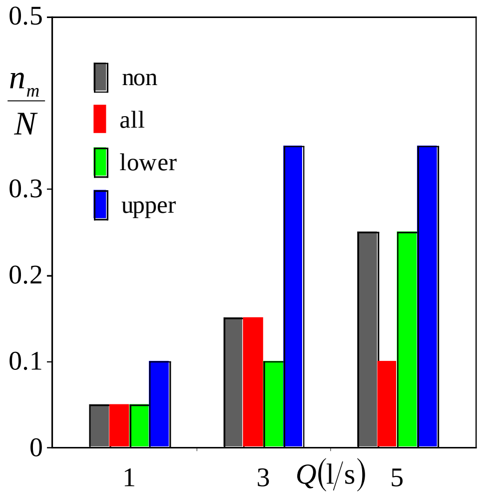


Figure 4, Migration rate of *Zacco platypus*

EXPERIMENTAL RESULTS AND ANALYSIS

Hydraulic properties at the bottom of pool

Figure 3 shows flow velocity V_V at the bottom (y/h=0.25) of second pool in this pool-and-weir fishway for 8 case (noQ1, alQ1, loQ1, upQ1, noQ5, alQ5, loQ5, upQ5).

Figure 3 (a), (b) show that there are the uniform flow at the bottom of pool in the case noQ1 and there are the fast flow at some points on the bottom of pool in the case alQ1. It is assumed that the placed boulders bring about decrease of the cross sectional flow area. Figure 3 (d) shows that there are the fast flow nearby boulders at the bottom of pool in the case upQ1.

Figure 3 (f), (g) (h) show that there are the low velocity flow area nearby boulders at the bottom of pool in the cases (alQ5, loQ5 or upQ5).

There are fast flow along the right side wall in each location patterns of boulders at Q=5(l/s), so the area ($0 \le x/L \le 1.0$, $0 \le z/B \le 0.2$) is defined as high velocity flow area.

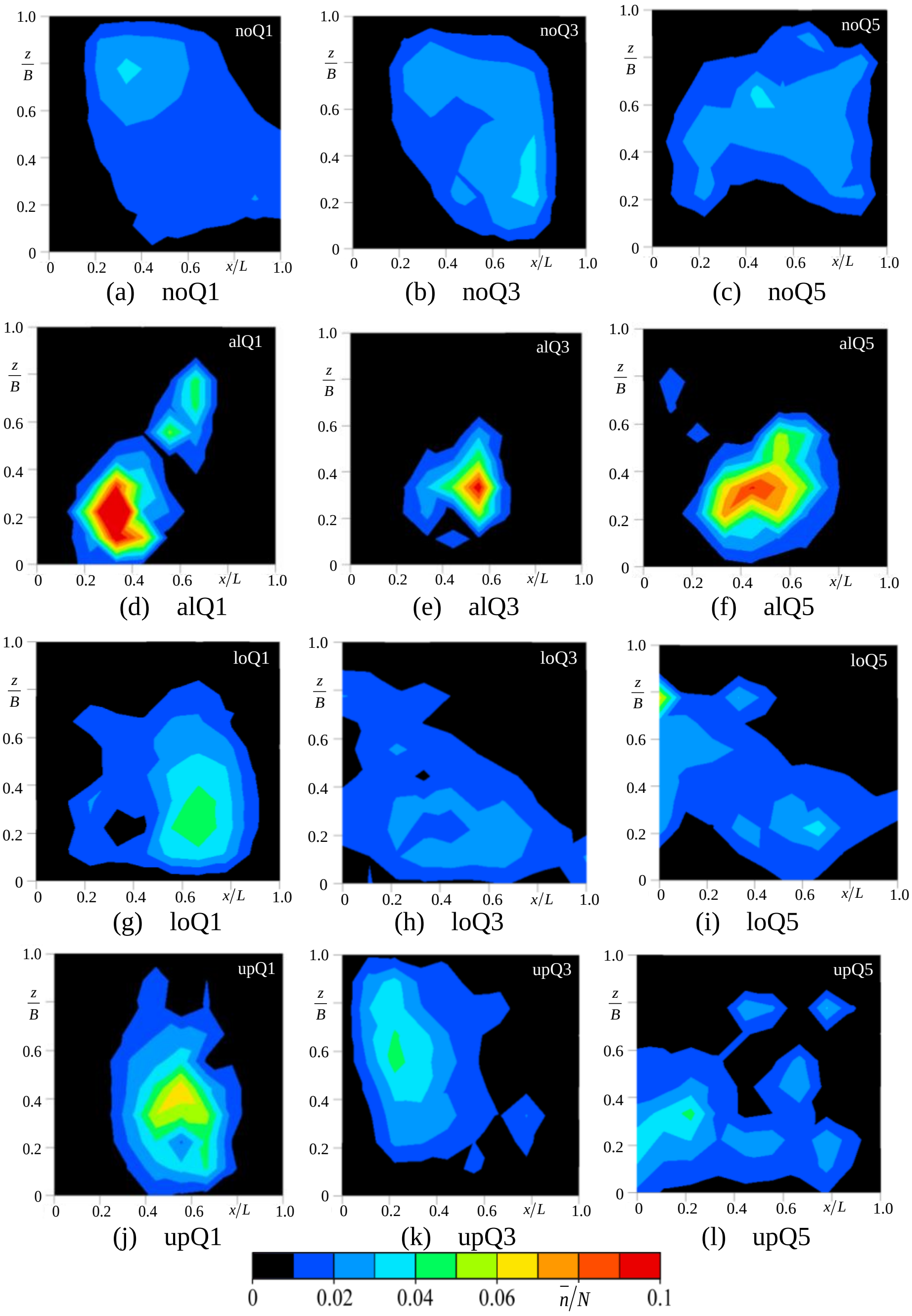


Figure 5, Projection chart of the existence rate

Migration rate of *Zacco platypus*

Migration rate was defined as following equation.

Migration rate =

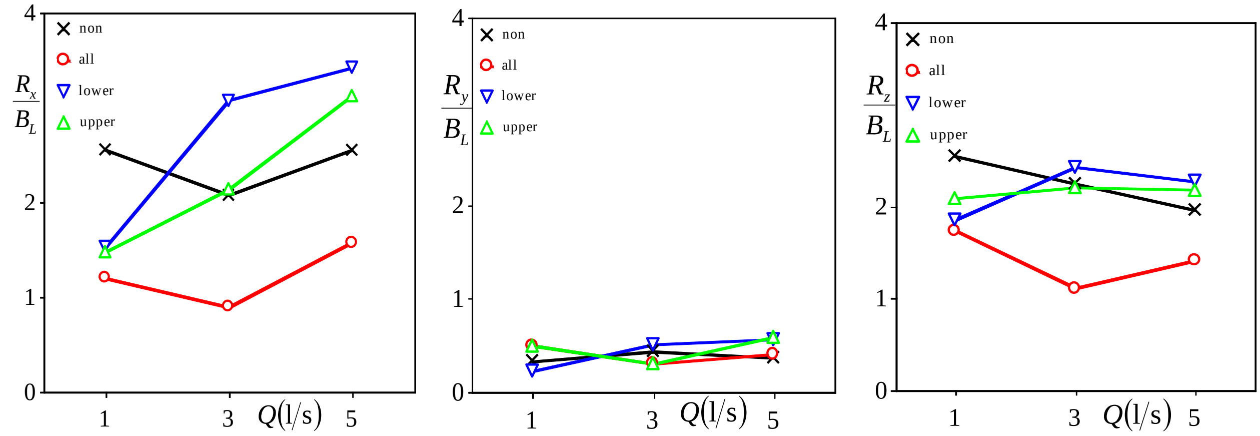
$$\frac{\text{Number of fish that succeeded in migration } n_m}{\text{Number of fish that used to experiment } N(=20)} \quad (1)$$

Figure 4 shows the correlation between discharge Q (l/s) and migration rate of *Zacco platypus*. The migration rate shows higher values in the pattern upper than any other case.

Change of the swimming properties in the pool

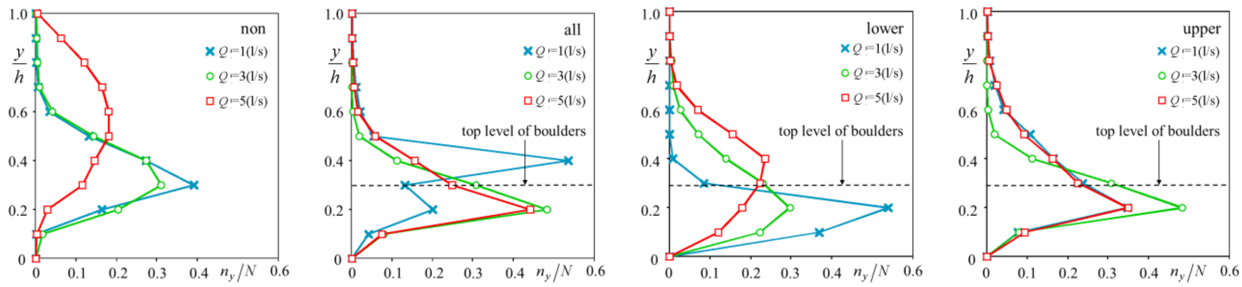
The horizontal section of the second pool is divided into the x direction, y direction in the range of the interval between 0.09m and 0.08m. The number of *Zacco platypus* each area every 10 seconds is counted, and the average number of *Zacco platypus* ($\bar{n}$) is calculated. Figure 5 shows existence rate of *Zacco platypus* each case at horizontal section (x-z). Figure 5(a) shows that small value of the existence rate ($\bar{n}/N$) spreads to the pool in the case noQ1. Figure 5(d) shows that large value of the existence rate ($\bar{n}/N$) is dense on the center of second pool in the case alQ1. Figure 5(g), (j) show results like figure 5(d). The small existence rate ($\bar{n}/N$) is distributed to the upper notch more in the case upQ1 than the case loQ1.

Figure 5(a)-(c) show that the existence rate ($\bar{n}/N$) is distributed to the upper notch of second pool more on high



(a) *x* axis (b) *y* axis (c) *z* axis

Figure 6, Radius of fish school at *x*, *y*, *z* directions



(a) non (b) all (c) lower (d) upper

Figure 7, Swimming frequency of *Zacco platypus* in *y* direction

discharge Q=5(l/s) than low discharge Q=1(l/s) in the pattern non. Figure 5(d)-(f) show that large value of the existence rate (n/N) is dense on the center of second pool within the all discharge Q=1, 3, 5(l/s) in the pattern all. Figure 5(g)-(i), (j)-(l) show that the distribution of the existence rate (n/N) spreads to x axis direction in the patterns lower and upper when discharge is large (Q=3, 5(l/s)).

Figure 6(a)-(c) show relations between radius of fish school in x, y, z directions (R_x , R_y , R_z) divided by average length B_L and discharge Q. Figure 6(a) shows that the remarkable change of x radius (R_x/B_L) by changing discharge is not observed in the pattern non. The remarkable change of x radius (R_x/B_L) by the discharge change is not observed in the pattern all and this x radius (R_x/B_L) is lowest of the all patterns (non, all, lower, upper). The larger discharge Q (l/s) is, the higher the x radius (R_x/B_L) is in the patterns lower and upper.

Figure 6(b), (c) show that the remarkable change of y and z radius (R_y/B_L , R_z/B_L) by changing discharge is not observed in the all patterns (non, all, lower, upper). When discharge Q (l/s) is larger, the fish spreads to the x direction, so fish gets less chance of swimming on high velocity flow area in the patterns lower and upper.

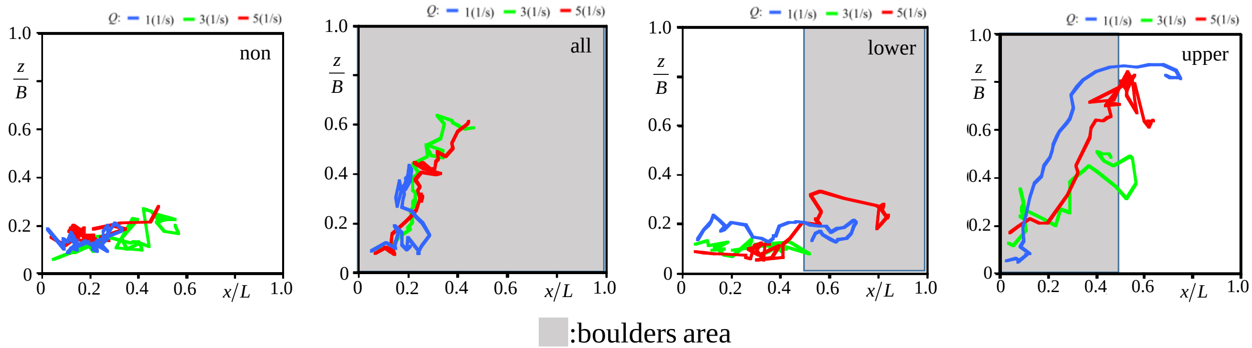
Swimming level of *Zacco platypus*

Figure 7 shows swimming frequency of *Zacco platypus* in y direction (n_y/N) for each boulders location patterns. The frequency (n_y/N) above y/h=0.5 at Q=5(l/s) is larger than Q=1, 3(l/s) in the pattern of non (Figure 7(a)), so increasing discharge raises swimming level of *Zacco platypus* in this pattern. The frequency (n_y/N) above the top of boulder at Q=1(l/s) is large, but the frequency (n_y/N) under the top of boulder at Q=3, 5(l/s) is large in the pattern all (Figure 7(b)). This result is suggested that *Zacco platypus* rests at the low velocity area nearby boulder to avoid fast flow by increasing discharge.

Increasing discharge raises the frequency (n_y/N) above the top of boulder in the pattern of lower (Figure 7(c)). The frequency (n_y/N) under the top of boulder at each Q is large in the pattern of upper (Figure 7(d)), so *Zacco platypus* swims between boulders in this pattern.

Change of migration route by boulders locations

Figure 8 shows the example of the 20 seconds migration route in each case at horizontal section (x-z). Boulders area is marked gray color. Fish migrates along the right side wall in the patterns non and lower. These migration routes are within the high velocity flow area. Fish migrates on oblique routes for the right side wall in the patterns all and upper. Therefore, the migration routes of the patterns all and upper are shorter than the patterns non and lower in the high velocity flow area($0 \le x/L \le 1.0$, $0 \le z/B \le 0.2$). Thus, it is that fish uses low velocity flow area nearby boulders for migration in the patterns all and



(a) non (b) all (c) lower (d) upper

Figure 8, Migration routes at horizontal section (*x*-*z*)

upper. It was confirmed that *Salvelinus leucomaenis leucomaenis* goes through around boulder for migration (2003). In this study, this experiment provide a similar result.

The number of all data is N_V =40 when the data is analyzed 20s before migrating every 0.5s. The number of data for each flow velocity V_V on passage points in 20s before migrating n_V is defined. The frequency distribution every flow velocity on the migration route n_V/N_V shows a most remarkable tendency within discharge Q=5(l/s) than Q=1, 3(l/s) since the flow velocity difference is largest on Q=5(l/s) in this study, so the discharge Q=5(l/s) is adopted. Figure 9 shows the frequency distribution every flow velocity on the migration route n_V/N_V in the cases (noQ5, alQ5, loQ5, upQ5). In the cases (noQ5, loQ5), the frequency n_V/N_V has a maximum value on V_V =0.25, 0.3(m/s). In the cases (alQ5, upQ5), the frequency n_V/N_V has a maximum value on V_V =0.15, 0.1(m/s), so there are the more frequency n_V/N_V on the low velocity flow area in the cases (alQ5, upQ5) than cases (noQ5, loQ5). It is understood that fish swims on a low V_V area in the cases (alQ5, upQ5). Figure 3 (e)-(h) and Figure 8 show migration routes of the patterns all and upper are shorter than the patterns non and lower in the high velocity flow area($0 \le x/L \le 1.0$, $0 \le z/B \le 0.2$). Therefore, migrating on the oblique route for the right side wall gives a little fatigue to fish. Thus, it is thought that migration rate has higher value on the large discharge Q=3, 5(l/s) in the pattern upper than the patterns non and lower.

CONCLUSIONS

In this study, migrating behaviors of *Zacco platypus* in pool-and-weir fishway were compared with the locations of boulders placed on the bottom of pool-and-weir fishway changed. The knowledge that this study provided is as follows.

(1) When boulders are placed on the bottom of all area in the pool, *Zacco platypus* swims in a small area nearby center of the pool.

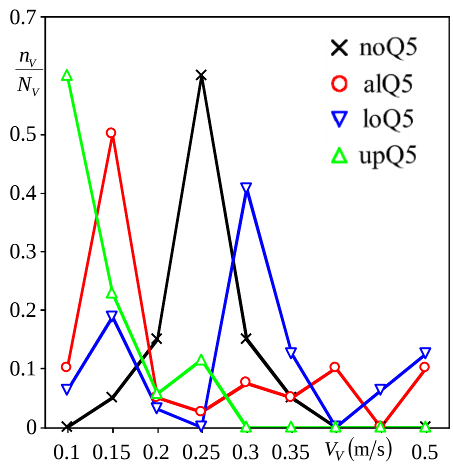


Figure 9, Frequency distribution every flow velocity on the migration routes

(2) When boulders are not placed on the bottom and placed on the bottom of lower in the pool, *Zacco platypus* migrates along the right side wall.

(3) When boulders are placed on the bottom of upper in the pool, increasing discharge, *Zacco platypus* rests in the low velocity flow area nearby boulders. Therefore, *Zacco platypus* migrates on oblique route for the right side wall.

NOMENCLATURE

B pool width, m
L pool length, m
H height from the pool bottom to a notch bottom, m
Δx thickness of the partition wall, m
Δy pool drop, m
Δz notch width, m
B_L *Zacco platypus* average length, m
V_V flow velocity, m/s
Q discharge, l/s
n_m number of fish that succeeded in migration
N number of fish that used to experiment
$\bar{n}$ average number of *Zacco platypus* each area every 10 seconds was counted

R_x , R_y , R_z radius of fish school at *x*, *y*, *z* directions, m

n_y/N swimming frequency of *Zacco platypus* in *y* direction

N_V number of all data analyzed 20s before migrating every 0.5s

n_V number of data for each flow velocity V_V on passage points in 20s before migrating

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