Journal of Hydroscience and Hydraulic Engineering
Vol. 17, No.1 May, 1999, 165-170

MIGRATORY BEHAVIOR OF JUVENILE AYU RELATED TO FLOW FIELDS IN DENIL AND STEEPPASS FISHWAYS

By

Kiyoshi Wada
Gifu National College of Technology, Gifu 501-0495, Japan

Nobuyuki Azuma
Hirosaki University, Hirosaki 036-8561, Japan

and

Shunroku Nakamura
Toyohashi University of Technology, Toyohashi 441-8580, Japan

SYNOPSIS

Portable Denil and Steeppass fishways (0.3m wide, 0.3m deep, 0.9m long) were installed on a diversion weir in the Okitsu river at City of Shimizu in Japan. The number of upstream migrating fishes to pass through the Denil fishway was found to be six times that of the Steeppass fishway. The mean body size of fishes passed through the Steeppass fishway, where the biggest fishes passed, was greater than that of fishes exiting the Denil fishway. The fishes prefer to regions of weak turbulent intensity without air bubbles and to migrate to the bottom region resting in pockets between baffles in the Steeppass fishway. For small fishes, the Denil fishway has the advantage of a slower velocity region near the bottom more than the Steeppass fishway. Our findings suggest that for juvenile Ayu the spacial size of the secondary circulation cells related to fish body length and turbulent intensity have an effect on migrating behavior in the fishways.

INTRODUCTION

Fishways are constructed to enable fish to overcome obstructions in rivers. Fishways are classified into three groups: stream-type, vertical slot and pool-and-weir fishways. For low head diversion weirs, stream-type fishways such as Denil, superactive bottom baffle fishway (Larinier pass) and Alaska Steeppass have been introduced in Japanese rivers. In these fishways, the hydraulic resistance and spiral circulation cells are controlled by obliquely arranged fins and/or baffles on the bottom and side walls, thus changing the flow pattern. Numerical analysis based on the k-ε turbulence model has been applied to the flow patterns in stream-type fishways by Tsujimoto (1).

Biological evaluation of the stream-type fishways was conducted to assess the functions of both fishways. An application of passive integrated transponder (PIT) technology has been used to monitor movements of adult fishes such as American shad (*Alosa sapidissima*), blueback herring (*A. aestivalis*) and gizzard shad (*Dorosoma cepedianum*) in the Denil and Steeppass fishways by Castro-Santos et al. (2). Visual observations and video records at several viewpoints were analytically used to make measurement data sets consisting population size, survival, passage efficiency and movement of migrating fishes. The relation between flow conditions and fish movements were then discussed based on the number of fish passed, ascending position, and swimming speed of upstream migrating juvenile Ayu (*Plecoglossus altivelis*) as they pass through two types of fishways.

LABORATORY TESTS

Two prototype fishways (portable Denil and Steeppass) were installed in a flume at the Gifu National College of Technology to measure the flow field in detail. The dimensions of the Denil and Steeppass fishways are shown in Figure 1. Photo 1 shows a complete view of the Denil and Steeppass fishway models in the hydraulic laboratory. Both fishways were 4.5m long, 0.3m wide and 0.3m deep. Both fishways were set up side by side at a slope of 1 on 5, as shown in

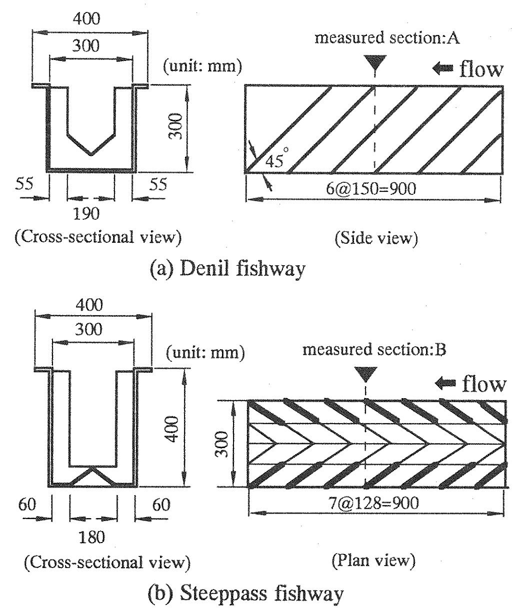


Fig. 1 Dimensions of the Denil and Steeppass fishways

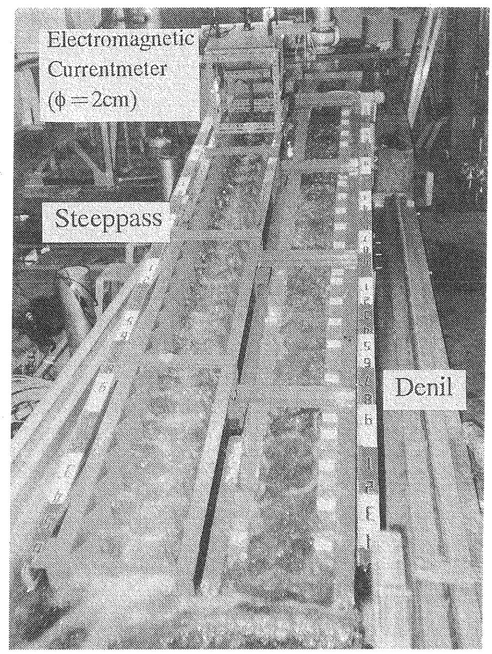


Photo 1 A complete view of the Denil and Steeppass fishways in the hydraulic laboratory

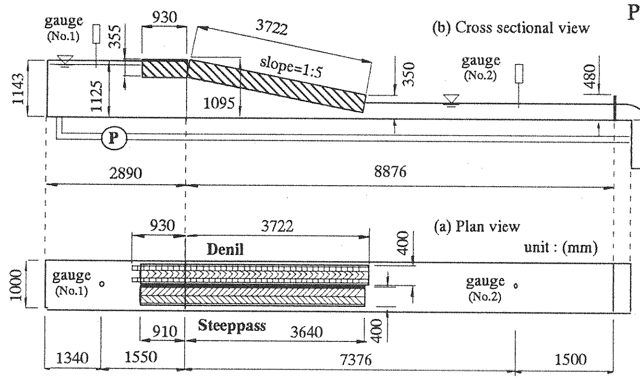


Fig. 2 Experimental set up in the hydraulic laboratory

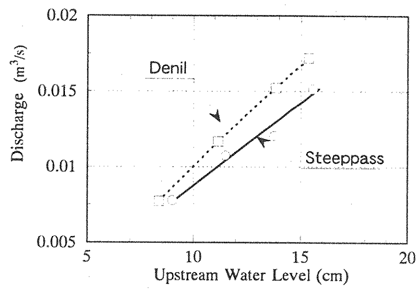
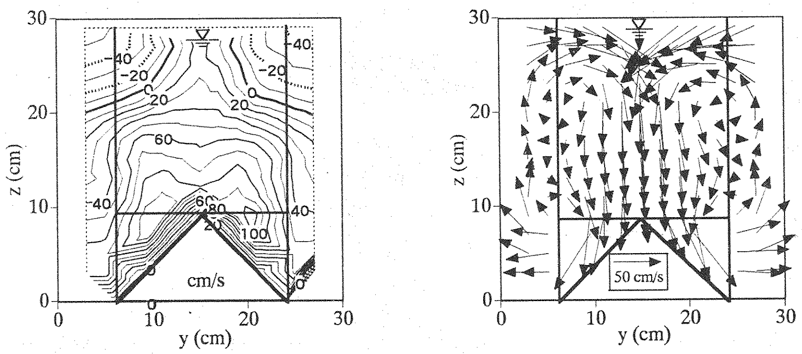


Fig. 3 Relation between upstream water level and discharge in the fishways

Figure 2. Flow discharge was varied from $0.012m^3/s$ to $0.021m^3/s$ for the Denil and $0.010m^3/s$ to $0.018m^3/s$ for the Steeppass. Three dimensional velocity components in both fishways were measured by an electromagnetic currentmeter (Model ACM-300, Alec Electronics: 2cm in diameter) at grid intervals of 2cm. Water surface profiles measured by servo-type wave gauges (Model SW-301, Kenek). All data were recorded for 90 seconds at 20Hz frequency and divided by sampling size to obtain an average reading.

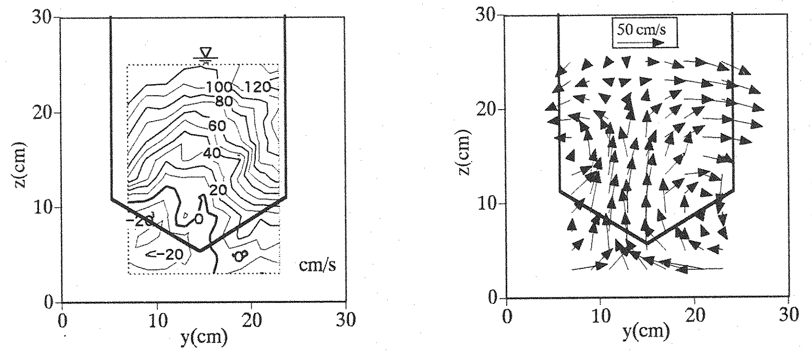
Flows in both fishways are controlled by fins and baffles on the bottom and side walls. These bring about higher hydraulic resistance to increase the total depth. Figure 3 shows the relation between the upstream water level and the discharge for the Denil and Steeppass fishways. The water level reference point is put on the bottom of the fishways. The Denil fishway carries 10 to 20 % greater discharge than the Steeppass for the same upstream water levels, and the Steeppass has a higher hydraulic resistance than the Denil fishway.

The measured values in both fishways are shown as the contour line of the downstream velocity U(y,z) in Figure 4(a) for the Steeppass fishway, Figure 5(a) for the Denil fishway, and the vector expression of cross and vertical flow components (V,W) in Figures 4(b) and 5(b), respectively. In the case of the Steeppass fishway, the downward flow along the centerline and the upward flow at both sides appear as shown in Figure 4(b) for a flow discharge of $0.018m^3/s$. As a result, the secondary flow forms a pair of symmetrical circulation cells. The most rapid downstream flow occurs near the bottom along the centerline. Similar downstream, cross and vertical flow patterns are observed at small discharges ($0.010m^3/s$).



(a) downstream velocity U(y,z) (b) cross and vertical velocities (V,W)

Fig.4 Contour line of the downstream velocity and the vector expression of cross and vertical velocities in the Steeppass fishway ($Q=0.018m^3/s$)



(a) downstream velocity U(y,z) (b) cross and vertical velocities (V,W)

Fig.5 Contour line of the downstream velocity and the vector expression of cross and vertical velocities in the Denil fishway ($Q=0.021m^3/s$)

In the case of the Denil fishway, the upward flow along the centerline and the downward flow at both sides appear as shown in Figure 5(b) for a flow discharge of $0.021m^3/s$. A pair of circulation cells is also observed in the Denil with comparatively asymmetric pattern, while the cross and vertical flow direction is in opposite to the Steeppass fishway. At small discharges ($0.012m^3/s$), however the downstream, cross and vertical flow patterns tend to remain symmetrical along the centerline. The most rapid downstream flow occurs near the water surface in contrast to the Steeppass fishway.

The average difference in the water surface elevation between the center and inside fins occurred at +3cm for the Denil fishway and -5cm for the Steeppass fishway. The positive sign signifies higher elevation at the centerline. The irregularities in the water surface are related to the direction of cross and vertical flow as the cross-stream surface slope results in a pressure gradient which drives the secondary circulation cells.

The fins are oriented obliquely to the longitudinal axis, thus changing the flow pattern. Flow without fins is driven by the longitudinal component of gravity, and vertical fins arranged perpendicular to the longitudinal axis simply act as resistance. However, if the fins are arranged obliquely, they cause vertical and/or transverse forces on the fluid which drive the secondary circulation cells. The velocity profile at the centerline of the Denil fishway is rather linear and wide, ranging from -20 to 120 cm/s proportionally to the height above the channel bed. These flow characteristics are caused mainly by the circulation cells driven by the oblique fins on the side walls, and the upward motion along the centerline which results in the linear profile of the downstream velocity. The flow in the Steeppass fishway is more complicated because of the mixed geometry.

The migratory behavior of small fish such as juvenile Ayu is affected by the primary and secondary flow magnitudes denoted by the flow velocity and the spatial size of the circulation cells, which is greater enough to catch and roll the small fish body in it.

EXPERIMENTAL RELEASE OF JUVENILE AYU

The experiment was conducted to understand the migratory behavior of juvenile Ayu that had a strong desire to

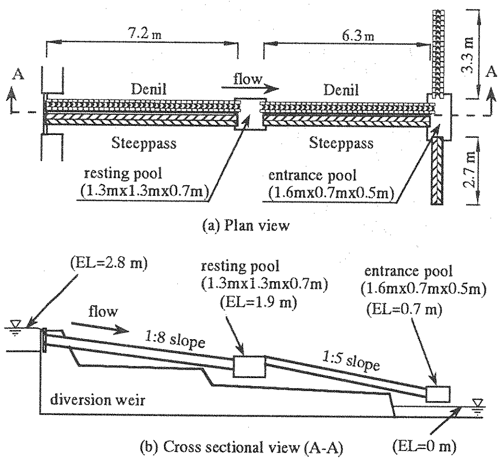


Fig.6 Experimental set up of the Denil and Steeppass fishways in the Okitsu River

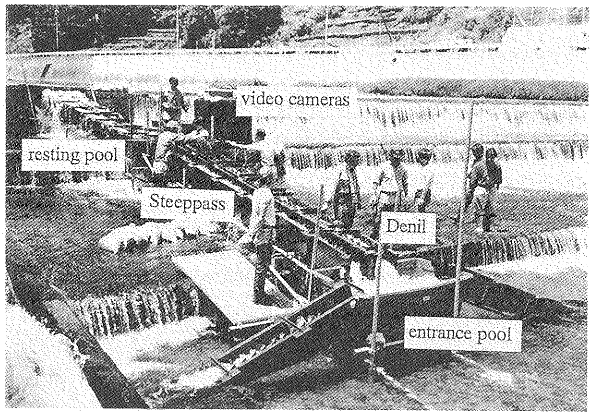


Photo 2 A complete view of the Denil and Steeppass fishways in the Okitsu River

Portable Denil and Steeppass fishways (0.3m wide, 0.3m deep, 18m long) were installed on an agricultural diversion weir (2.8m head, 54m wide) in the Okitsu river at the foot of Mt. Fuji in Japan on 26 May 1995. Figure 6 shows the two fishways set up side by side on the Okitsu river. They were installed at two different slopes of 1 to 5 and 1 to 8 as shown in Figure 6. Total length including the entrance and resting pools was 18m. Photo 2 shows the field experimental set up of the Denil and Steeppass fishway models in the Okitsu river.

Two kinds of juvenile Ayu were used in the experiments. Wild Ayu were collected in June of 1995 at a weir 1 km upstream from the mouth of the Ado river, a tributary to Lake Biwa. Hatchery Ayu that were raised Shizuoka Fisheries Experimental Station were also used. The juvenile Ayu grow to lengths of 5 to 7 cm while wintering in the sea and ascend the rivers in the spring where they mark out territories of around 1 m^2 in the rapids of the middle to upper reaches of the rivers and feed on the algae by scraping them off the rocks with their jaws.

A total of 133 hatchery Ayu were released into the entrance pool, then observed by underwater video cameras and captured at the exit of the fishways. Water temperature during the experiment ranged between 13 and 20 degrees centigrade. The mean body length and weight of juvenile Ayu were 9cm and 8g, respectively. Figure 7 shows the relation between body size and number of fish passed at the middle resting pool and the exit. At the middle resting pool, both fishways totally passed 16.5% of the released hatchery fishes in the first stage of the fishways. The mean body size of passed fish was broadly distributed as shown in the figure. The whole body size were distributed over a wide range around the mean body size. At the upper section, however, only 3 % of the fish passed both fishways and exited at the top. The mean body size in the Steeppass, which passed the biggest of the fish was greater than that in the Denil. The flow conditions in the Steeppass seemed to be inadequate to pass the hatchery Ayu.

About 400 wild Ayu were released in the entrance pool on 23 June 1995. Underwater video cameras were installed in the middle resting pool. The time variation of the number of ascending fish per one minute is shown in Figure 8. The number of fish increased immediately after the gate at the entrance pool was opened to both fishways. In the Steeppass, the number of fish decreased suddenly to a few fish shortly after release. The number of fish entering the Denil changed intermittently with increased periods every twenty minutes. The total successful passage rate was more than 50% in one hour for both fishways. The number of fish in the Denil was six times higher than in the Steeppass. The Denil flow conditions were easy for juvenile Ayu to ascend, though thirty one wild Ayu successfully passed through the Steeppass.

Figure 9 shows ascending positions of the wild fish in cross sections of both fishways, using video data. Each point represents the head on Ayu through the cross section. In the Denil fishway, most fish used the lower part of the baffle around the V-shape arrangement where slower velocities existed. As the vertical velocity profile was shown earlier, the flow velocity increases in accordance with the height above the channel bed. The larger fish could therefore find a portion further from the bed than the areas near the bed where smaller fishes prefer. Air bubbles created by the hydraulic turbulence near water surface could be another difficulty for ascending fish as the upstream view of swimming fish was interrupted.

In the Steeppass, most Ayu passed next to the lower part of the side walls. Air bubbles were observed at every point in the fishway creating bed visibility. A faster primary velocity field is generated on the bottom at the centerline corresponding to the region of faster downward flow. As a result of the hydraulic conditions, juvenile Ayu ascended along

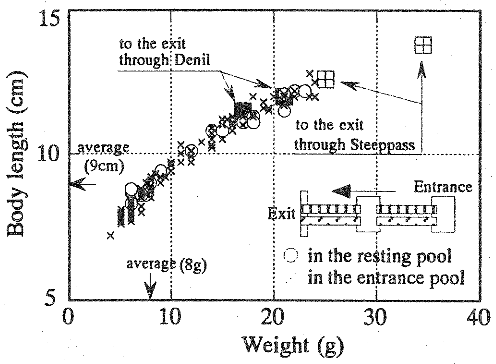


Fig.7 Relation between body size and number of fish passed at the middle resting pool and the exit (hatchery Ayu)

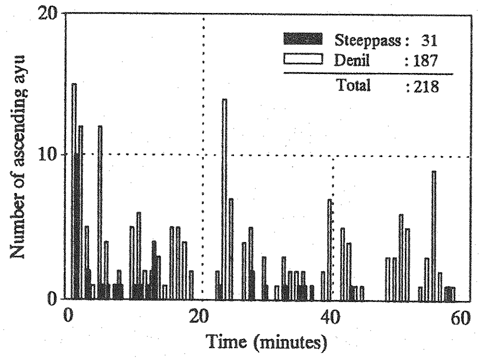


Fig.8 Time variation of the number of fish passed per one minute to the middle resting pool (wild Ayu)

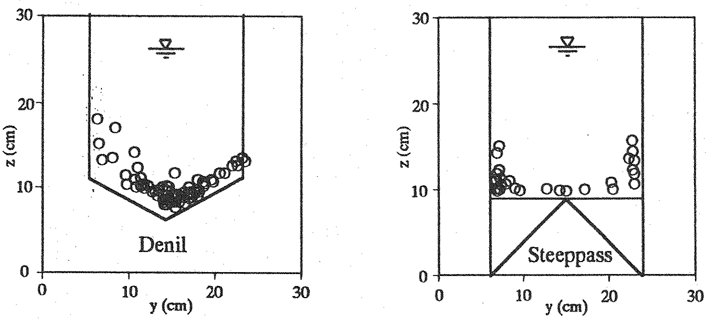
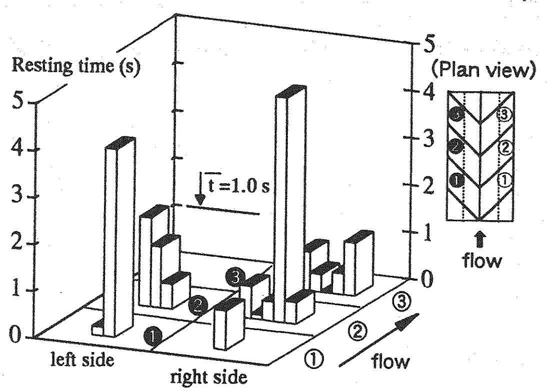


Fig.9 Migrating positions of Ayu in cross sections of both fishways (wild Ayu)



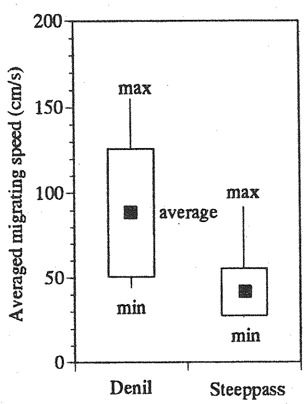


Fig.10 Average migrating speed of Ayu in the Denil and Steeppass fishways (wild Ayu)

Fig.11 Resting time in the bottom right and left pockets in the Steeppass fishway (wild Ayu)

a zigzag course, resting at some pockets along the bottom and side wall fins.

Figure 10 shows that the average migrating speed of Ayu in the Denil fishway is compared with the Steeppass fishway by use of initial video data for two minutes. Seventeen Ayu passed through the Denil fishway and twelve Ayu moved without resting anywhere. For the Steeppass fishway, fourteen Ayu passed and only one fish ascended without a rest. The fish migrated quickly on the bottom centerline where the transverse velocity was smaller than the primary and downward flow. Because many Ayu rest in the Steeppass fishway, the average migrating speed is smaller than the Denil fishway and the distribution of total migrating speed is broad in the Denil fishway. The resting time in bottom right and left pockets for the Steeppass is shown in Figure 11. The average resting time was about one second and Ayu rested inside most pockets within the three blocks divided by vertical fins. Some fishes were caught in pockets containing a small vortex generated by the fins. As a result, they stayed in the pocket over thirty seconds.

CONCLUSION

This study was conducted to investigate the relationship between the flow and fish migration to check the suitability for small fishes in the Denil and Steeppass fishways. In these fishways, the hydraulic resistance and circulation cells are controlled by obliquely arranged fins. Both fishways have some contrastive hydraulic characteristics for primary, secondary (spiral flow) velocity fields and water profile. The aspect ratio of depth to width is near unity, much air bubbles existed at upper half region. Based on the field observations with a different aspect ratio (two times), juvenile Ayu remained to migrate through lower region (see e.g. Wada et al.(3)). It was often observed that some fish passed through the bottom region even in the Steeppass fishway which had faster flow near the bottom. There is a tendency for juvenile Ayu to ascend around the lower part in both fishways. The fish tend to prefer regions of weak current without air bubbles in both fishways and to migrate near the bottom region making good use of pockets between baffles in the Steeppass. The Denil fishway has the advantage of a slower current region near the bottom for small fishes. It is pointed out that for juvenile Ayu scale of secondary circulation cells related to fish body length and turbulent intensity have an effect on migrating behavior in the both fishways.

REFERENCES

1. Tsujimoto T.: Numerical analysis for aid to understand the flow structure of stream-type fishways, Proceedings of the International Symposium on Fishways '95 in Gifu, pp.49-56, 1995.
2. Castro-Santos T., A. Haro and S.E. Walk: A passive integrated transponder (PIT) tag system for monitoring fishways, Fisheries Research 28,pp.253-261, 1996.
3. Wada K., Nakamura S. and Azuma N.:Hydraulics of a composite fishway with pool and stream types -Field observation and evaluation-, Proceedings of the International Symposium on Fishways '95 in Gifu, pp.237-242,1995.

(Received October 9, 1998 ; revised January 8, 1999)