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A FIELD SURVEY ON FLOW CHARACTERISTICS AND ASCENDING OF FISHES IN ICE-HARBOR TYPE FISHWAY OF MITUMENAI HEADWORKS

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SYNOPSIS

Experimental study on the relation between the the ascent of fish and the hydraulic characteristics was carried out in the ice-harbor type stepped fishway (width: 3.0 m, drop: 0.15 m, slope: 1/16, length: 116.8 m) of Mitsumenai headworks on the Mitsumenai River in the Iwaki river system, one of the A-class rivers in Aomori Prefecture. Seven fish species, mainly consisting of dace (*Tribolodon hakonensis*) (97.6%) and common fat-minnow (*Moroco steindachneri*) (1.5%), were confirmed to ascend the fishway. When there was flow over the notches, fish tended to ascend mainly through the notches. On the other hand, when there was no overflow over notches, fish were confirmed to ascend through the orifices, from which the orifices were confirmed as functioning as passage facilities as well as at the time of overflow over notches. The hydraulic characteristics in the fishway were clarified from the three-dimensional composite vector distribution of flow-velocity and the two-dimensional composite vector distribution of flow-velocity each within the pools in the fishway.

INTRODUCTION

In recent years, river improvement programs have been carried out from the standpoint of preserving river ecosystems. In this situation, some cases have been found where the function of headworks fishways, which are intake weirs for agriculture, is reduced due to the lowering of the riverbeds downstream from the headworks or the facilities becoming superannuated. Thus, the reconstruction of fishways has been conducted in many regions. In addition, the view of maintaining the fishway environment as a part of the river flow is being emphasized (1), so that selecting the form of fishway adapted to the geographical and hydraulic characteristics specific to the river and the ecosystem condition has become important.

Studies on fishways have been carried out in all fields including headworks fishways and weir fishways (2 - 5). However, research on the ascending of fish through headworks and the related hydraulic characteristics have been limited to the investigation of the ascending of fish through stepped fishways, the effect of hydraulic characteristics of fishways on ascending, and so forth, and the number of reports concerned is small (6,7). Especially, there are few cases where the flow state in fishways was investigated in detail based on on-site measurements. Meanwhile, grasping the relation between the ascending behavior of fish and the hydraulic characteristics in a fishway is very important. Therefore, research on these subjects is being promoted as seen in the reported case concerned with the relation between the flow characteristics and the ascending behavior of ayu-fish fry in a deniel-type fishway (8).

Amid such background, the authors have conducted an on-site investigation for an existing headworks fishway and have grasped the actual conditions (9). It is highly significant to clarify the relation between the

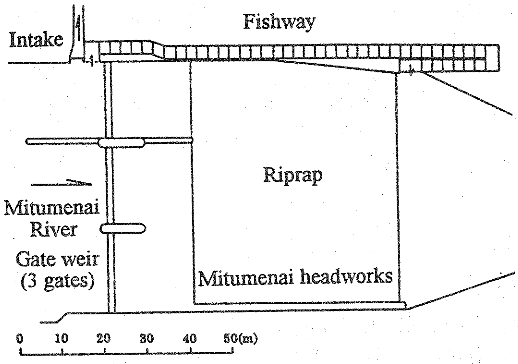

Fig.1 An overview of the Mitumenai headworks

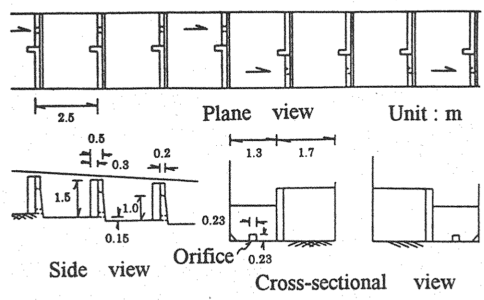

Fig.2 An overview of the ice-harbor type fishway

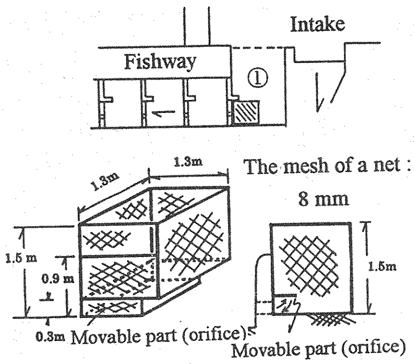

Fig.3 Trap point and net cage

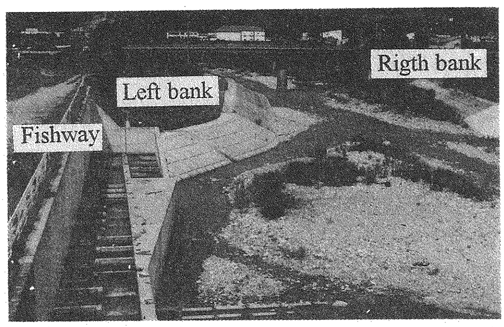

Photo.1 The situation downstream of headworks

actual state of ascent through various reconstructed fishways and the hydraulic characteristics due to the structure of the fishways from the viewpoint of designing fishways in the future in combination with the effect of the fishway on the ascent.

This report presents the result of an on-site investigation dealing with a reconstructed ice-harbor type stepped headworks fishway, concerning the ascent of fish in a period of irrigation water intake and the hydraulic characteristics of the fishway, and considers the relation between the hydraulic characteristics and the effect of the fishway on the ascent.

OUTLINE OF THE INVESTIGATED HEADWORKS FISHWAY

The fishway investigated for ascent is an ice-harbor type stepped fishway in the Mitsumenai headworks established on the Mitsumenai River within the river system of the Iwaki River, one of the first-class rivers in Aomori Prefecture. This headworks is situated about 80 km upstream from the mouth of the river. The fish subject to fishery rights belong to 8 species which include ayu fish (*Plecoglossus altivelis*), white-spotted char (*Oncorhynchus masou f. ishikawae*), carp (*Cyprinus carpio*), crussian (*Carassius spp.*), Japanese common char (*Salvelinus leucomaenis pluvius*), dace (*Tribolodon hakonensis hakonensis*), rainbow trout (*Salmo gairdnerii f. iridens*) and Japanese sculpin (*Cottus hilgendorfi*). Fig. 1 and Photo. 1 show an overview and the situation of Mitumenai headworks, respectively. The weir is a fully movable weir (18m × 3), 60.55m in total length. An intake is situated on the left bank of the river, and a fishway is situated just downstream near the intake. The length, width and gradient of the fishway are 116 m (18.3 m to the turn), 3.0 m and 1/16.6, respectively. There are 44 partitions in the fishway. Fig.2 shows an overview of the ice-harbor type stepped fishway. Each partition has a notch, 0.5 m in height and 1.3 m in width, and an orifice with a square section of 0.23 m × 0.23 m. The downstream side of the notch has a sectional shape of 1/4 the arc of a circle. Notches and orifices are arranged alternately by 4 pools. The drop between adjacent partitions is 0.15 m, and the interval between pools is 2.5m.

Downstream from the headworks, a bank sand is found at the central part of riverbed protection equipment as seen in Photo. 1. When river water flows down only through the fishway, the water level at the entrance of the fishway is continuous with that of the downstream left bank water route, and, thus, a submerged region is not formed in the immediate downstream of the movable weir. When the flowing river water is abundant, however, water also overflows over the movable weir, and the water flow is typically divided into two parts, with the bank sand at the central part of riverbed protection equipment between the two parts.

METHODS AND ITEMS OF INVESTIGATION

Investigations of the ascent of fish in the fishway were conducted 11 times in total in the period of irrigation-water intake, from May to September in 1997 and 1998. The method of collection in which a net cage was set at the exit of the fishway is shown in Fig. 3. The net cage was taken out every 2 hours during a 24 hour period (from 10 a.m. to 10 a.m.), and fishes which had ascended through the fishway and entered into the net cage were collected. Here, the fish collected in the net cage were treated as those that had ascended through the fishway. As the number of ascended fishes was too small for collection, two collection times were omitted in the period from midnight to early morning.

The items of investigation were as follows: number of fish species collected, number of fish collected, length and weight of fish collected, river water quality (temperature, turbidity, dissolved oxygen, electric conductivity), intensity of illumination, air temperature, flow rate for the fishway, flow velocity at the notch and orifice of the partition at the exit of the fishway, the respective depths of water at the notches, at the upstream and at the downstream of partitions, and distribution of flow velocity. Though the net cage had a structure which took into consideration the ascent through notches and orifices combined, the structure was modified so as to be able to collect the fish ascending through notches and orifices separately for the investigation in 1998. The measurement of flow velocity for monitoring the flow rate was conducted at the fishway exit (refer to Fig. 3,①: 9 points), and the flow velocity at each point was measured by a uni-axial electromagnetic flow meter (ACM-3D, Alec Electronics, Co.). In addition, the measurement relating to the ascent route through notches was also conducted partially by setting a video above the notches.

Apart from the investigation of the ascent of fish, the measurements of flow velocity in the fishway were taken by using a three-axis electromagnetic flow meter (ACM-300, Alec Electronics, Co.) in hydraulic conditions of both flowing over the notches and flowing down only through the orifices. Measurements were taken in transeverse, longitudinal and vertical directions at 112～140 points in total. In the condition of flowing down only through the orifices, the orifice exit sections were measured in detail (25 points).

RESULTS AND CONSIDERATION

Actual conditions of the fish ascent

Table 1 shows the dates of examining the ascent, the weather on the days of examination, and the ranges and averages of air temperature and water temperature, respectively. The weather on the days of examination generally tended to be cloudy or rainy in 1997, and fine or cloudy in 1998. The average river-water temperature ranged from 13.7℃ to 18.1℃ in 1997, and from 14.3℃ to 19.1℃ in 1998. It was low in May in both years.

Table 2 shows the species and number of ascending fish on each day of examination. The ascending fish belong to 7 species, among which dace occupied the largest proportion, accounting for 98%, and then common-fat minnow, white-spotted char and Japanese common char in decreasing order. However, no ayu fish as a useful species were caught. The number of ascending fish per examination in the two-year period of investigation was about 100. Though the examination dates were the same between the two years, the number of ascending fish was different by year and by period. For example, the number of ascending fish on May 19 in 1997 was extremely large, amounting to 545. As a reason for this, it is considered that the oviposition and migration period of dace coincided with the examination date, because dace are generally said to lay their eggs in the period from spring to early summer when water temperature is about 13℃ (10, 11). As an investigation by capture was not done in the river, the ratio of fish ascending through the fishway is unknown. Asterisks in the table indicate the case where the river water flowed down only through the orifices owing to the lowering of the water level. These numerals with asterisks indicate that fish were able to ascend through the orifices even in the above case.

Regarding the effect of the reconstruction of the fishway on the ascent of fish, although it can not be confirmed because the actual ascent situation before the reconstruction is unknown, the effect is inferred to be present from consideration of the results of this investigation and the fact that the water level at the fishway entrance is continuous with that of the water route in the downstream river, as shown in Photo 1. Such fish as ayu fish and Japanese sculpin were not confirmed in this investigation as stated above. It will be necessary to confirm hereafter the ascent of these fish species by investigation at lower reaches of the river and ascent experiments involving the release of fish. Here, the ascent characteristics shown are mainly those of dace, because most of the as-

Table 1 Subsequent survey days and weather conditions

Subsequent survey day		Weather	Temperature(℃) Range	Temperature(℃) Average	Water temperature(℃) Range	Water temperature(℃) Average
'97	5/19～5/20	rain after sunshine	9.4～20.4	14.4	10.4～17.9	13.7
	6/ 2～6/ 3	rain after sunshine	11.6～19.9	14.5	11.6～17.1	14.2
	7/14～7/15	rain after cloudiness	20.1～27.3	22.0	16.8～19.4	18.1
	8/11～8/12	cloudiness	19.1～24.9	22.7	15.3～16.6	15.8
	9/ 1～9/ 2	cloudiness	21.1～26.5	22.4	16.7～19.6	18.1
	9/15～9/16	cloudiness	11.4～20.0	15.5	13.3～17.2	15.3*
'98	5/18～5/19	sunshine after cloudiness	14.2～20.7	17.9	12.8～15.9	14.3
	6/ 8～6/ 9	cloudiness	12.1～20.8	16.0	13.2～18.3	15.6
	7/13～7/14	sunshine	14.0～26.9	19.1	13.4～18.9	15.9
	8/10～8/11	cloudiness after sunshine	15.4～24.8	20.5*	16.8～20.8	19.1**
	8/31～9/ 1	sunshine after cloudiness	15.7～24.1	19.2	13.9～15.4	14.6

Note:Measurement value of each hour from 10:00 am to 10:00 am the next day.
*,**:Measurement value excepting 12:00 am -5:00 pm and 3:00-5:00 pm,respectively.

Table 2 Fish species and number of ascending fish

Fish species	Route	May	June	July	August	September		Sum
1997								
Japanese dace		537	24	63*	172	22	7	825
Japanese fat-minnow		7	—	2*	—	—	—	9
Trout		—	—	2*	—	—	—	2
White-spotted char		—	2	—	—	—	—	2
Japanese char		1	—	—	—	—	—	1
Pike gudgeon		—	—	—	—	3	—	3
Sum total		545	26	67*	172	25	7	842
1998								
Japanese dace	Notch	26	*	25	*	98		149
	Orifice	5	98	—	18	22		143
Japanese fat-minnow	Notch	—	*	2	*	—		2
	Orifice	—	—	—	6	—		6
Trout	Notch	—	*	1	*	—		1
	Orifice	—	—	—	—	—		—
White-spotted char	Notch	1	*	—	*	—		1
	Orifice	—	—	—	—	—		—
Japanese mitten crab	Notch	—	*	1	*	—		1
Sum	Notch	27	*	29	*	98		154
Sum	Orifice	5	98	—	24	22		149
Sum total		32	98*	29	24*	120		303

*: Hydraulic conditions of non overflow on the notch.

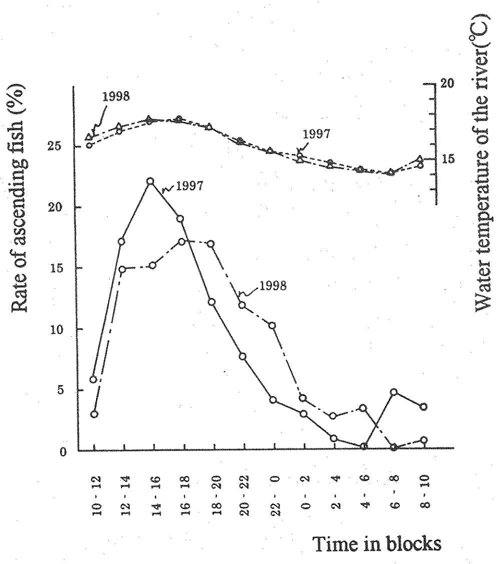

Fig.4 Change in the number of ascending fish over time

cending fish were dace.

Fig. 4 shows the change in the number of ascending fish throughout the whole investigation with the passage of time. The daily time zone in which ascending was most frequent was generally from afternoon to just after sunset (about 8 p.m.), though it differed between examination days. The number of ascending fish in this time zone accounted for 60% or more of the daily total. The number of ascending fish tended to be very small from midnight to early morning, showing a similar tendency as in the fishway of the unified headworks on the Iwaki River belonging to the same river system as the Mitsumenai River (9). This tendency was associated with the pattern of change in the number of ascending daces. The examination of the relation between the river-water temperature and the ascent of fish through the fishway showed that the river-water temperature from midnight to early morning, during which the number of ascending fish was small, tended to be low for the day as seen in Fig. 4. Ecological factors are thought to be related to the daily periodicity of the behavior of fish (12), while water temperature is surmised to have an effect on the ascent of fish.

Ascending route

The examination of the ascent route over the notches and through the underwater openings in the case where water flowed over the notches showed that 85% of the fish preferred to ascend over the notches, as shown in Table 2. Regarding the ascent over notches, it was reported that the ratio of the fish ascending over the notches was 80% in the experiment for ayu fish in an overall-overflow type fishway (5), and 85% in the investigation for chum salmon (*Oncorhynchus keta*) in an ice-harbor type fishway (13). The result of this investigation is interesting in that the tendency for selecting the ascent route was similar to that of chum salmon, though the species are different from each other. It was also shown that the orifices were utilized as a route for ascending in both the cases of flowing over the notches and flowing only through the orifices. Though the purpose of orifices is the use by bottom-level fish, they are considered to be a useful passage facility for a swim-ming fish such as dace.

Next, an examination was carried out into which part of the notch is used as the ascent route by taking video pictures of the parts for ten hours. Fig. 5 shows the proportion of the ascent divided between 4 sections of the notch at the fishway exit. The number of fish ascending through both the section near the sidewall and the section near the part of the partition other than the notch accounted for about 80% and the number ascending through the central part was small, as illustrated in the figure. In this respect, fishes have been said to pass near the sidewall (5). However, as described below, at the central part downstream of this type of notch, there is a water flow which flows out from the orifice just downstream as well as an overflow water vein from the notch. Therefore, this is also considered to be a factor affecting the ascent route.

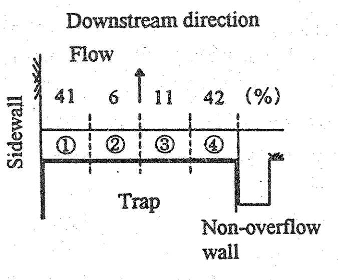

Fig.5 The proportion of the ascending route

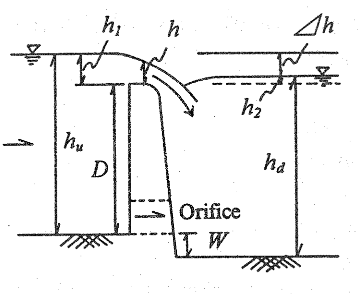

Fig.6 An outline of hydraulic condition

Table 3 Hydraulic conditions

(unit : m,s)

Survey day	h_1	h_2	h_2/h_1	Δh	h	Q_{obs}
'97 5/19~5/20	0.14	—	—	—	0.12	0.265
6/ 2~6/ 3	0.11	—	—	—	0.10	0.102
7/14~7/15	—	—	—	0.14	—	0.064
8/11~8/12	0.22	0.05	0.23	0.17	0.20	0.398
9/ 1~9/ 2	0.11	0.09	0.09	0.10	0.11	0.251
9/15~9/16	0.13	0.01	0.08	0.12	0.12	0.259
'98 5/18~5/19	0.08	—	—	0.15	0.08	0.142
6/ 8~6/ 9	—	—	—	0.17	—	0.055
7/13~7/14	0.15	—	—	0.16	0.13	0.221
8/10~8/11	—	—	—	0.15	—	0.069
8/31~9/ 1	0.21	0.05	0.24	0.18	0.18	0.450

Note:Average measurement value every 2 hours from 10:00 am to 10:00 am the next day,Qobs:Measured value 1 time each survey day.

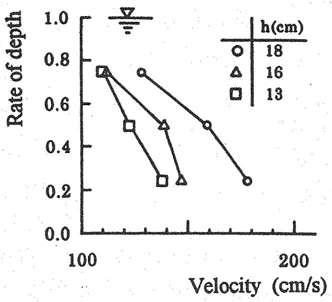

Fig.7 Vertical distribution of velocity over the notch

Hydraulic conditions of fishway

Fig. 6 shows water flows at the partition of the fishway, and Table 3 shows the hydraulic condition on each examination date. The discharge in the fishway ranged from 55 l/s to 450 l/s and varied somewhat depending on the date and time of examination. Water depth at the notch ranged from 8 - 20 cm except in the case where water flowed down only through the orifice, and the difference in water level between the front and the back of the notch was nearly equivalent to the difference in elevation between the pools, which was 15 cm.

The condition of overflow over the notch represented a condition of complete overflow so that the ratio of the water level downstream (h_2) to that upstream of the notch (h_1) was less than two thirds, as shown in Table 3. The water vein was smooth because the section of the notch was formed into 1/4 the arc of a circle. The average velocity measured at the notch and that at the exit of the orifice was 81 - 155 cm/s and 130 - 173 cm/s, respectively.

From the examination of the distribution of flow velocity in the vertical direction, it was shown that the flow velocity in the lower layer increased with the increasing depth of water as shown in Fig. 7, and that the flow velocity in the upper layer was lower than that in the lower layer by about 30%, so that the distribution of flow velocity was similar to that over the crest (14).

In general, the ice-harbor type fishway has an advantage that the water flow in the whole pool is not disturbed owing to the existence of the non-overflowed part. However, an increase in the overflow depth (by more than 20 cm in this case) as a hydraulic condition might cause the overflow vein to effect the water flow to the downstream partition in some cases. Therefore, it seems to be important to establish the length of the pool according to the fluctuation of the water level. As the partitions in every 4 pools are arranged to make the position of their notches reciprocal to that of the adjacent 4 pools, the difference in the water level between the group of pools is considered to reduce the flow velocity.

Regarding the design of fishways, the hydraulic condition at the notch is associated with the swimming speed and the burst speed of fish (15), and the burst speed standard has been generally assumed to be 10 times the fish body length (16,17). Thus, the respective relations between the distribution of the body length of ascending fish and the water depth and flow speed at the notch, and the flow speed at the orifice were examined. Table 4 shows an example of the distribution of fish body length by the ascent route. The average values were calculated from the histogram of body length divided by 1 cm as weighted averages. The body lengths of fish ascending through the orifices tended to be a little larger than those of fish ascending over the notches in the case of overflowing over the notches, whereas smaller fish also ascended through the orifices in the case of flowing down through the orifices only.

Assuming temporarily that the value into which the flow velocity is divided by the body length of fish

Table 4 Body length distribution of the ascending fish (1998)

(unit :cm)

Month	Fish species / Route	Japanese dace Range	Japanese dace Average	Japanese fat-minnow Range	Japanese fat-minnow Average
May	Notch	8.0 ~ 16.0	11.0	----------	
	Orifice	10.0 ~ 14.0	12.4	----------	
June	Notch	----------		----------	
	Orifice	5.0 ~ 18.0	9.4	----------	
July	Notch	5.0 ~ 16.0	10.6	6.0 ~ 9.0	7.5
	Orifice	----------		----------	
August	Notch	----------		----------	
	Orifice	4.0 ~ 15.5	7.9	5.0 ~ 6.0	5.5
September	Notch	9.0 ~ 25.0	13.6	----------	
	Orifice	11.0 ~ 20.0	14.4	----------	

Table 5 The mid-body length of fish as well as depth and veloity

Survey day	(Notch) Depth	Range of velocity	Average	Range of swimming burst speed factor (cm/s/*BL*)*	(Orifice) Range of velocity	Range of swimming burst speed factor (cm/s/*BL*)**
1998	(cm)	(cm/s)			(cm/s)	
5/18~5/19	8	——	81	10~5 (7)	113~175	11~8 (9)
6/8~6/9					146~175	29~8 (16)
7/13~7/14	13	106~144	122	24~8 (12)		
8/10~8/11					147~180	37~10 (19)
8/31~9/1	18	128~178	155	17~6 (11)	145~195	13~7 (10)

* :Value obtained where average velocity in the notch is divided by the body length (minimun and maximun) of the ascending fish.

**:Value obtained where smallest velocity in the orifice is divided by the body length (minimun and maximun) of the ascending fish.

( ) is divided by average body length.

represents the burst speed factor, the burst speed factor was calculated using any one of the minimum, maximum and average values of the fish body length derived from the frequency distribution of fish body length on the dates of examination (refer to Table 5). Here, for the calculation of the flow velocity, the average was used for the flow over the notch because the flow velocity changed in the vertical direction, whereas the minimum of the values measured at 9 points of the section was used for the flow through the orifice. The values in parentheses showing the range of the burst speed factor were calculated using the averages of the body length. Though the burst speed seems to differ among fish species, it can be seen that the fish ascended even in a flow whose velocity was more than 10 times their body length. However, because it is not known which part of the local flow area the fish preferred to pass through, it is possible that the fish ascended through the section at which the water flowed slowly.

Distribution of flow velocity and the flow state in fishway pools

It is very important to grasp the relationship between the ascent behavior of fish and the hydraulic conditions in fishways for designing fishways, as reported by Wada et al. (8). Figs. 8(a), (b) show the flow states in the pools generally as a three-dimensional vector distribution of flow velocity in both the cases of flowing over the notches and flowing down through the orifices, respectively.

The hydraulic conditions in the case of flowing over the notches were as follows: discharge at flowing down: 325 l/s, water depth in the pool: 115 cm, overflow depth over the notch: 14 cm. Figs. 9 (a), (b) show the two-dimensional vector distribution of flow velocity in the direction of flow down at the central part of the notch (just above the orifice) and at the spot 35 cm away from the center of notch in the direction of the right bank, respectively (numerals in figures are compound values of two vector directions). Generally, the

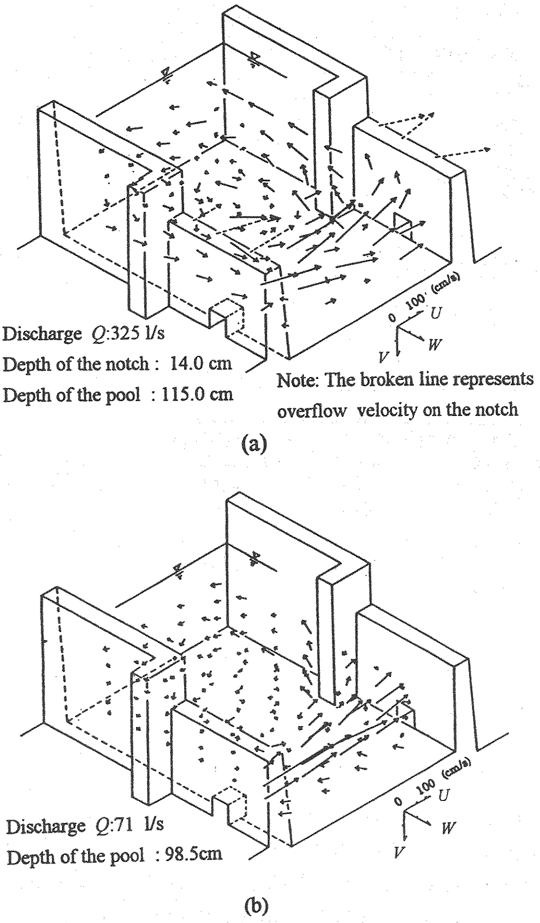

Fig.8 The three-dimensional distribution of velocity in the pool

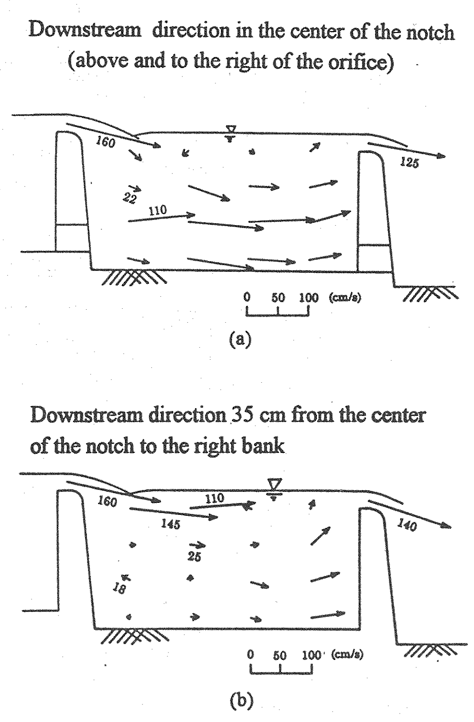

Fig.9 The two-dimensional distribution of velocity (for overflow on the notch)

water flow over the notch reached the partition of the lower step as latent flow, and formed a rotary flow in the pool. In the flow down direction at the central part of the notch, the flow by the overflow vein and the flow by flowing out through the orifice below the notch were distinguished, while at the spot not affected by the orifice an upward flow was formed at the area immediately downstream of the notch, as shown in Fig. 9 (b). The flow velocity near the bottom surface was relatively low. Besides, a flow in the lateral direction along the partition at the non-overflow part arose to form a small rotary-flow region where the change in flow velocity was small so that fish seemed to rest there. On the contrary to the most ice-harbor type fishway which has two notches and two orifices on the partition, the said fishway has one of each. Therefore, hydraulic conditions are considered to be good, showing an unexpectedly calm flow state at the pool between the non-overflow parts of partitions.

The flow state in the case of flowing down only from the orifices (flowing down discharge: 71 l/s, water depth in the pool: 98.5 cm) showed that in the direction of the non-overflow parts, a calm rotary-flow region was formed where the flow velocity was extremely slower than that in the case of overflowing over the notches, though there was a flow flowing out straight from the orifices as shown in Fig. 8 (b). Next, the component of the flow velocity(U) in the flowing down direction was measured by a three-axis flow-velocity meter at 25 points (mesh of 4.5 cm × 5 cm) of the section of the orifice exit under this condition. Fig. 10 shows the flow-velocity line at the orifice exit. The flow velocity at the central part was 195 cm/s, faster than that near the sidewalls, however, was as slow as 10 cm/s at the corners of the orifice. It varied significantly depending on the points of measurement, and its standard deviation was as large as 40 cm/s, which is considered to be caused by the spiral turbulent flow due to the contraction within the orifice.

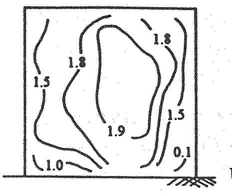

Fig.10 An example of the velocity distribution (in the outlet cross-section of the orifice)

In summary, the following is inferred from these hydraulic conditions and the route of ascending fish through the notches: fish take a rest in areas within the non-overflow sections where water flow is calm. Then, (i) in the case of overflowing over the notches, fish ascend through the region which is found immediately downstream of the notches other than their central parts, where the flow velocity is upward and slow (see Fig. 9 (b)), or through the notches and orifices, (ii) in the case of flowing down only through the orifices, fish take a rest at the non-overflow areas, and then wait for a chance to ascend through the upstream orifices. Since fish as small as about 5 cm in body length ascended through the orifices, it is necessary to examine the route within the orifices hereafter.

In the course of the investigation, cases were often found where rubbish (vinyl bags in particular) flowed down into the fishway and choked the orifices. As it has been established from this investigation that the orifices function at times of small discharge, measures to prevent rubbish flowing down into fishways (for example, a floating screen to cover the surface part of water at the fishway exit) should be considered, and maintenance of the facility is considered very important.

CONCLUSION

An on-site investigation was carried out for the ascending fish and the hydraulic characteristics in an ice-harbor type stepped fishway reconstructed during the irrigation period, and the effect of the fishway on the ascent of fish was examined. The ascent of dace as the main species was confirmed in this fishway, and the functioning of the orifices was also established. As such fish species as ayu fish and Japanese sculpin were not confirmed, however, a follow-up survey hereafter including the survey of inhabitants in the lower reaches of the river and the experiment of fish ascent by release is necessary.

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REFERENCES

1.Kashiwai, J.：Meaning and Design Subject of Fishway, JSCE, Vol.83, pp.49-51, 1998(In Japanese).
2.Sasanabe, S.：Fishway of Headworks, Vol.1, 279p., Sasa Printing Co., Hirosaki, 1989(In Japanese).
3.Sasanabe, S.：Fishway of Headworks, Dam technology, 39, pp. 43-56, 1990(In Japanese).
4.Sasanabe, S.：Fishway of Headworks, Vol.2, 311p., Sasa Printing Co., Hirosaki, 1996(In Japanese).
5.Nakamura, S., N.Takasima and H.Kimura：On the experiment on the flow characteristics in the pool-weir stepped type fishway, Vol.55-10, JSIDRE, pp.933-998, 1987(In Japanese).
6.Sato, R., S.Sugawara, K.Otuka and J.Ando：Study on Upstream Migration of Ayu Fish and Chum Salmon Through a Weir-type fishway at a Dam across the Lower Part of the Naruse River, Fishes Engineering, Vol.29 No.2, pp.123-126, 1992 (In Japanese).
7.Kaneko, Y., K.Isumi, M.Tuthiya and Y.Otake：Hydraulic Characteristics and Ascending Effectiveness of the Fishways In AkikawaRiver, Ann.Jour.Hydr.Eng., JSCE, No.41, pp.265-270, 1997(In Japanese).
8.Wada, K., N.Asuma and S.Nakamura：Migratory Behavior of Juvenile Ayu Related to Flow Fields In Denil and Steeppass Fishways, Ann.Jour.Hydr.Eng., JSCE, No42, pp.499-504, 1998(In Japanese).
9.Izumi, M., N.Kawagoshi, A.Kudo and W.Mikami：A Field Survey on Ascending Fishes and Hydraulic Characteristics in a Pool-weir Fishway of Headworks, JSIDRE, Vol.66(10), pp.55-60, 1998 (In Japanese).
10.Tamai, N., N.Mizuno and S.Nakamura：River environment ecology, pp.40-42, Univ. of Tokyo Publication Association, Tokyo, 1997 (In Japanese).
11.Kawanabe, H. and N.Mizuno：River and fish of the lake, pp.140-145, Hoikusya,Tokyo, 1996 (In Japanese).
12.Mizuno, N. and K.Mise： Ecology of the river,pp.168-170, Tukijisyokan, Tokyo, 1993(In Japanese).
13.Onodera, O., H.Misawa and K.Shindo:Ascending effect of the salmon in the ice-harbor type fishway, Electric Power Civil Engineering, No.276, pp.14-18, 1998 (In Japanese).
14.Hino, M.：The Hydraulics,Maruzen, Tokyo, 1983 (In Japanese).
15.Hirose, T. and C.Nakamura：Design of The Fishway, pp.170-171, Sankaido, Tokyo, 1991(In Japanese).
16.Inoue, M.：Action and fishing method of the fish, pp.155-159, Koseisya koseikaku, Tokyo, 1978 (In Japanese).
17.Tukamoto, K. and T.Kajiwara：Swimming velocity and swimming performance of the fish, Fishes Civil Engineering, Vol.10, No.1, pp.31-36, 1973 (In Japanese).

APPENDIX - NOTATION

The following symbols are used in this paper:

h_1 = overflow depth
h_2 = downstream depth
$\triangle h$ = water-level difference between the upstream and downstream levels
h = depth of the notch
Q_{obs} = discharge for the fishway
h_u = upstream water depth
h_d = downstream water depth
D = height of the notch
W = drop by step
BL = body length of ascending fish

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