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Development of a New Fishway for Various Fish Species and Cost Reduction

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Abstract

Recently, environmental conservation has been considered to be a more important part of the design of irrigation barrages than before. In this study, we investigated the spatial patterns of local flow velocity, etc. in a fishway with orifices (hereafter referred to as "orifice fishway") to improve the performance for fish migration. The results showed that an orifice fishway enabled to achieve a more convenient maintenance through the use of a short baffle span and to obtain short migration routes for various fish species on a steeper slope of 1:4.5 and with a lower discharge of 0.12 m^3/s compared with most of the currently used fishways by the improvement of "partially superimposed orifices", even if the upstream or downstream water level changed.

Discipline: Irrigation, drainage and reclamation/ Fisheries/ Agricultural engineering
Additional key words: headwork, hydraulic design, orifice

Introduction

Recently, environmental conservation has been considered to be a more important part of irrigation projects than before. Accordingly, it is essential that various fishes, including non-fishery species, be able to migrate over irrigation barrages. It is also important to harmonize the improvement of the fishway performance with operations of the irrigation barrage. To achieve these objectives, attempts were made to improve a submerged orifice fishway which is a kind of artificial fishway (Fig. 1). Symbols used in this paper are listed in Table 1.

Principle of new fishway

Requirements for the harmonization are shown in Table 2[13], and the conditions required for fish migration are shown in Table 3[1–4,6–9,11,12]. To meet these conditions, we tried to improve a submerged orifice fishway because it might enable to save the discharge, stabilize the flow for the change of head or tailwater level, prevent blockage by drifting materials and bird predation, although the configuration is not natural. However, it is difficult to make the slope steeper than that of other artificial fishways. To improve this aspect, we tried to shorten the baffle span to a fixed drop between adjacent pools[14](Fig. 2). On the other hand, attempts were made to partially superimpose adjacent orifices instead of adopting a linear arrangement to prevent excessive acceleration of the velocity through the orifice (hereafter referred to as "orifice velocity") and to ensure that the superimposed area is suitable for large fish migration through the orifices.

Experimental methods

Improvement of a submerged orifice fishway was achieved through hydraulic model tests based on Froude's similarity. All the data in this paper were converted into prototype size to observe the fishway performance more conveniently. The configuration of the partial model, the whole model and measurement points in these models are shown in Figs. 3 and 4. Scale of these models is 1:2, 1:5. Measurement points of the pool water level in the whole model were located at four corners of the pools and those of the head water level were located along side walls at 0.25 m upstream from No.1 baffle. Pool depth in the partial model, pool water level in the whole model, discharge, horizontal velocity, vertical velocity in both models were measured, respectively, using a point gauge, a scale, weirs, a propellor current meter with a diameter of 0.005 m and an electro-magnetic current meter with a diameter of 0.004 m (model size). Measurement time of velocity was 60 seconds at intervals of 1 second in model size.

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Table 1. Symbols used in this paper

B : Orifice width.

B.S. : Burst speed of a fish.

B_s : Superimposed width between adjacent orifices.

C.S. : Cruising speed of a fish.

Δh : Average drop of water level between adjacent pools.

$\Delta(V_{xyz})$: Possible maximum fluctuation range of V_{xyz}.

$$\Delta(V_{xyz}) := (V_{xyz})_{max} - (V_{xyz})_{min}.$$

F_h : Average fluctuation range of water level at pool corners.

G.V. : Maximum velocity for rest of goby and cottus.

h : Average pool depth.

h_d : Average depth of the tail pool.

h_u : Average depth of the head pool.

K_1 : Height value required for migration.

K_2 : Height value required for rest.

K_a : Height required for migration of a fish.

K_f : Fish height except for dorsal and ventral fins.

K_r : Height required for rest of a fish.

L_2 : Length value required for rest.

L_f : Fish length except for a caudal fin.

L_r : Length required for rest of a fish.

Q : Discharge.

q : Unit discharge.

R_h : Relative pool depth to h_u . $R_h = h / h_u$.

S_r : Superimposed width ratio ($= B_s / B \times 100$).

V : Flow velocity.

V_o : Sectional average orifice velocity.

V_1 / V_2 : Composite velocity of V_x , V_z at measurement points M1/ M2 (Fig. 4) in an orifice.

V_3 / V_4 : Composite velocity of V_x ,V_y , V_z at measurement points M3/ M4 (Fig. 4) in a pool.

$(V_1)_{av} / (V_2)_{av}$: Average value of $(V_{xz})_{av}$ at measurement points M1/ M2 in each orifice.

$(V_1)_{max} / (V_2)_{max}$: Maximum value of $(V_{xz})_{av}$ at measurement points M1/ M2 in each orifice.

$V_x / V_y / V_z$: Velocity component in the longitudinal/ transverse/ vertical direction with a positive sign in the downstream direction/ in the direction of the close side wall/ in the downward direction.

$(V_{xyz})_{av}$: Composite velocity of each average value of V_x , V_y , V_z in a series of measurement times.

$(V_{xyz})_{max} / (V_{xyz})_{min}$: Composite velocity of each maximum/ minimum absolute value of V_x , V_y , V_z in a series of measurement times corresponds to possible maximum/ minimum value of V_{xyz} .

W_1 : Width value required for migration.

W_2 : Width value required for rest.

W_a : The least width required for migration of a fish.

$(W_a)_{max}$: Probable maximum value of W_a.

W_r : The least width required for rest of a fish.

$(W_r)_{max}$: Probable maximum value of W_r .

Table 2. Requirements of fishways in irrigation barrages

Requirements for environmental conservation
(1) Migration of various fish species from large to small fish, goby, cottus (2) Prevention of excessive predation by birds, carnivorous fish (3) Approximation to natural configuration, natural flow state
Requirements for both improvement of fishway performance and operations of the irrigation barrage
(4) Preservation of fishway performance in low river discharge (5) Preservation of fishway performance for change of head and tailwater level (6) Stability of fishway discharge for change of head and tailwater level (7) Preservation of fishway performance on steep slope or high drop
Requirements for operations of the irrigation barrage
(8) Estimation of fishway discharge for change of head and tailwater level (9) Reduction of construction cost*1 (10)Easy and inexpensive maintenance*2
Requirements for other aspects
(11)Prevention of excessive obstruction to flood passage (12)Harmonization with surrounding natural scenery

*1: The steeper, the shorter and the more inexpensive for the fixed drop.

*2: Excessive blockage by drifting materials, drifting sand and gravels should be avoided.

Table 3. Conditions required for migration and rest of a fish

Conditions required for migration route of a fish
(1) $V \leqq$ B.S.*1 (m/s) = L_f (m) ×10 (= L_f (m) ×7 (goby, cottus)) (2) W_1*2 $\geqq W_a$*3 , $(W_a)_{max} = L_f \times 0.5$ provided that V = B.S. (3) K_1*4 $\geqq K_a$, $K_a = K_f \times 1.2$ $L_f / 3.5$.
Conditions required for rest space of a fish*5
(4) $V \leqq$ C.S.*6 (m/s) = L_f (m) ×4 $V \leqq$ G.V. with goby, cottus (G.V. (m/s) L_f (m)) (5) Enough space for fish rest 5-a) W_2*7 $\geqq W_r$*8, $(W_r)_{max} < L_f \times 0.5$ provided that V = C.S. or G.V. (goby, cottus). 5-b) K_2*9 $\geqq K_r$, $K_r = K_f \times 1.2$ $L_f /3.5$. 5-c) L_2*10 $\geqq L_r$, $L_r = L_f \times 1.2$.

*1: Maximum time for B.S. is a few seconds.

*2: W_1, Width of migration route fulfills (1).

*3: W_a, Swinging width of a caudal fin in migration. W_a increases with the increase of the swimming speed .

*4: K_1, Height of a migration route fulfills (1).

*5: Rest space is required provided that the swimming time exceeds the maximum time of the swimming speed.

*6: Maximum time for C.S. is 30 minutes.

*7: W_2, Width of a rest space fulfills (4).

*8: W_r, Swinging width of a caudal fin in rest. W_r increases with the increase of the flow velocity (V).

*9: K_2, Height of a rest space fulfills (4).

*10: L_2, Length of a rest space fulfills (4).

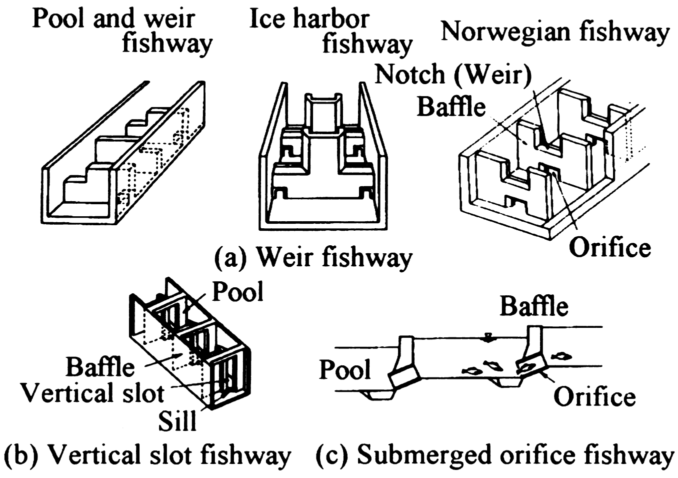


Fig. 1. Classification of artificial fishways (pool type)

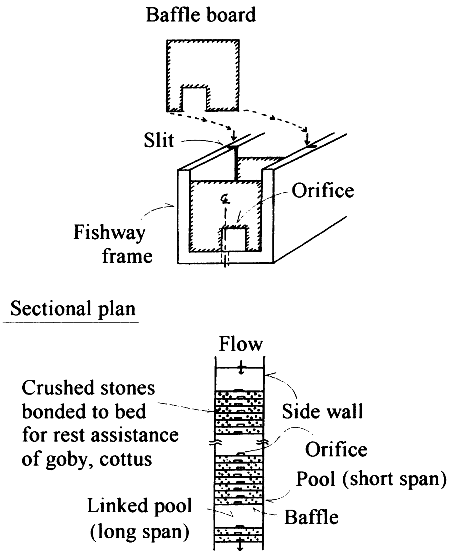


Fig. 2. Proposal for a fishway for various fish species and cost reduction

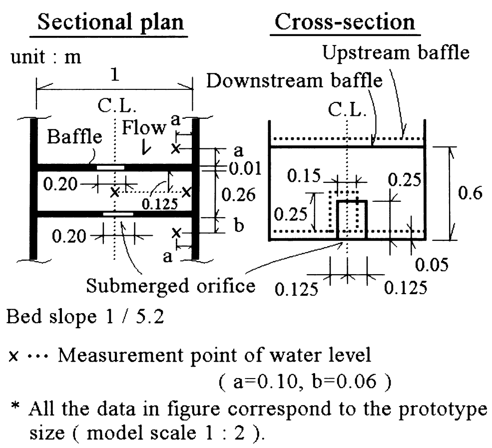


Fig. 3. Partial model of a submerged orifice fishway

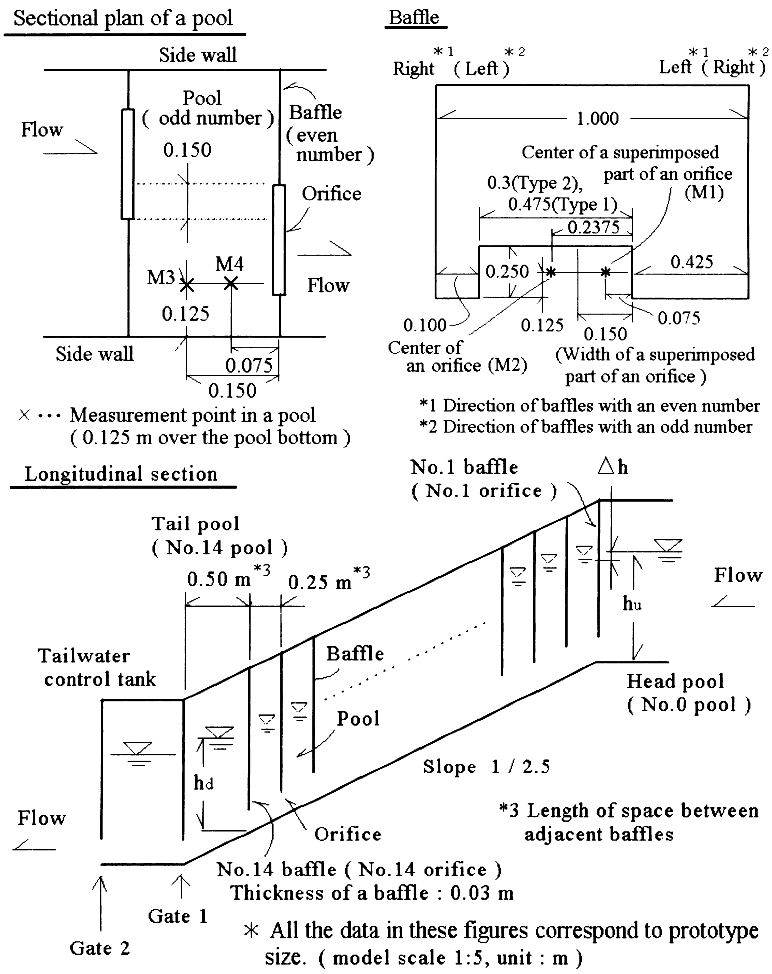


Fig. 4. Whole model of a submerged orifice fishway

Experimental results

- Local flow downstream of an orifice in the partial model: Examples of $(V_{xyz})_{av}$ contours downstream of an orifice are shown in Fig. 5.
- Flow state in the whole model: Submerged orifice flow state could not be maintained when the orifice width (B) was not sufficient for the fixed superimposed width (B_s = 0.15 m) required for large fish migration. Under these conditions, the average pool depth (h) in the upstream part of the model was relatively low because most of the upstream orifice flow directly passed through the next downstream orifice in these pools. This problem was solved in Type 1 model in which B = 0.475 m and S_r = 31.6 %.
- Pool depth and discharge in Type 1: Difference in h in each pool was not appreciable and decreased with the increase of h. Discharge (Q) was almost constant independently of h (Table 4).
- Drops and fluctuations of the pool water level in Type 1: Drops between adjacent pools (Δh) changed in each pool, but the difference was within ± 0.02 m except for the orifices at both ends. Average drop was about 0.1 m. Under these conditions, the fluctuation range (F_h) in each pool increased with the decrease of h but never exceeded 0.045 m.
- Orifice velocity in Type 1: The difference in velocity at the center of an orifice (V_2) was not appreciable in each pool and the average value was about 0.7 m/s (Fig. 6). Velocity at the center of a superimposed area in an orifice (V_1) ranged from 1.4 to 1.9 m/s but the velocity did not increase downstream.
- Fluctuations of orifice velocity in Type 1: Possible maximum fluctuation range of the orifice velocity is shown in Fig. 7. The V_z value at M1, M2 was almost constant and nearly 0 m/s. The V_x value at M1 was almost constant but that at M2 sometimes decreased to 0 m/s.
- Velocity and its fluctuations in a pool of Type 1: Velocity and its fluctuations near the pool bed (at M3, M4) were almost constant regardless of the h value (Fig. 8) and constant in all the orifices provided that h ≧ 0.8 m. This is because No.1 and No.7 pools in Fig. 8 were located downstream of No.1 and No.7 orifices where the minimum and maximum values of the orifice velocity and its fluctuations were recorded at M1 when h = 0.8 m (Figs. 6 and 7).

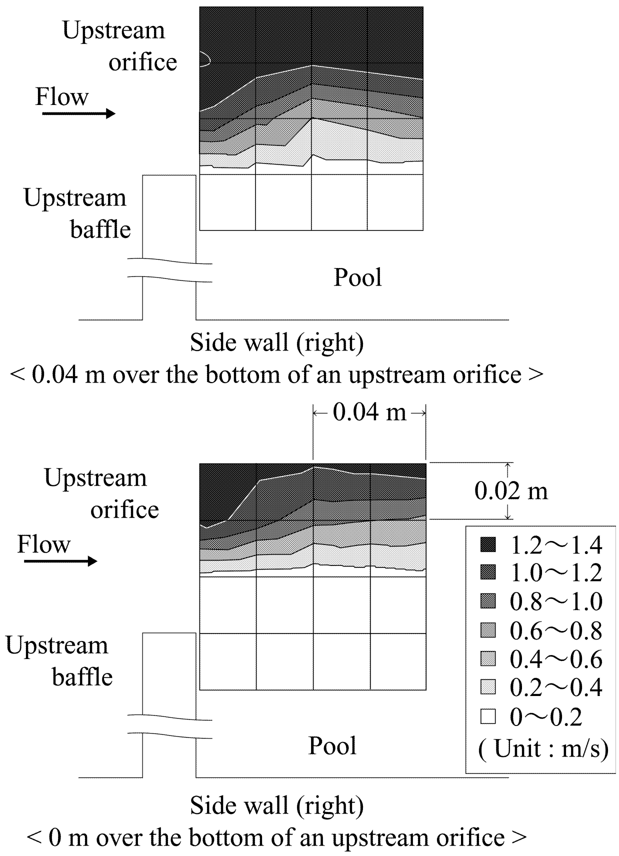


Fig. 5. $(V_{xyz})_{av}$ contours downstream of the upstream orifice in the partial model
(Prototype size, Δh = 0.094 m, h = 0.480 m, Vx = 1.21 m/s at the center of the orifice)

Considerations regarding the final configuration of the fishway (Type 1 fishway)

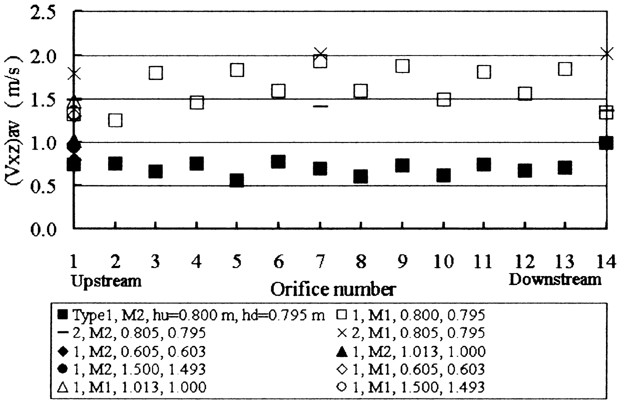
1. Hydraulic characteristics

Hydraulic characteristics are summed up and described as follows.

(1) The relative fluctuations of the pool water level (F_h/h) and the differences in each pool increased with the decrease of the h value, especially when h 0.6 m, because Q and the sectional average orifice velocity (V_o) were almost constant regardless of the h value (Table 4). Therefore it is considered that flow disturbance and the difference in each pool increased with the decrease of the h value.

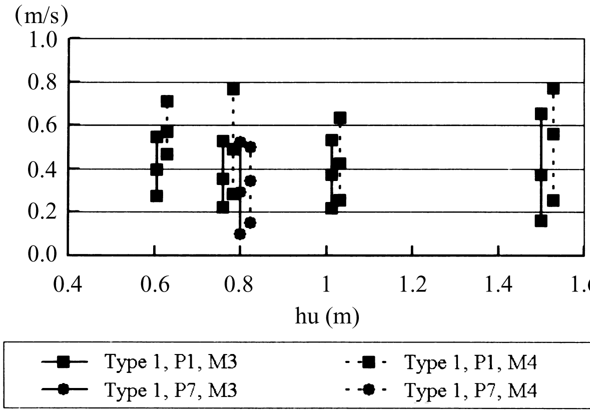
Table 4. Discharge, velocity in the whole model (Type 1, prototype size)

h_u (m)	0.608	0.800	1.013	1.500
h_d (m)	0.623	0.795	1.000	1.493
Q (m^3/s)	0.103	0.108	0.111	0.111
V_o (m/s)	0.868	0.913	0.936	0.931
$(V_1)_{av}$ (m/s)	–	1.620	–	–
$(V_2)_{av}$ (m/s)	–	0.710	–	–



* $(V_{xz})_{av}$: Composite velocity of each average value of Vx , Vz in a series of measurement times. M1 : Measurement point at the center of a superimposed part in an orifice. M2 : Measurement point at the center of an orifice.
h_u : Average depth of the head pool. hd : Average depth of the tail pool.

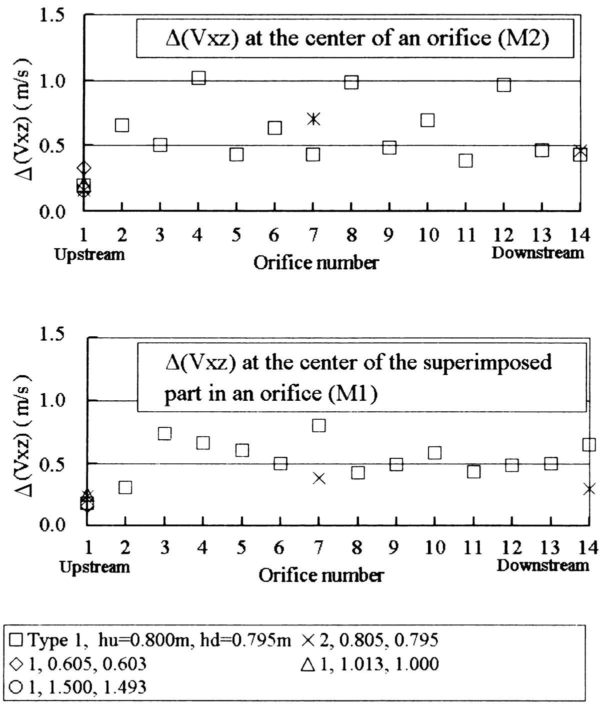
Fig. 6. Orifice velocity in the whole model (prototype size)



* hu: Average depth of the head pool. P1, P7 : Pool No. 1, 7
M3 : Upstream measurement point of velocity in a pool
M4 : Downstream measurement point of velocity in a pool

Fig. 8. $(V_{xyz})_{max}$, $(V_{xyz})_{av}$, $(V_{xyz})_{min}$ in a pool of the whole model (Type 1, prototype size)

(2) The difference in Δh in each baffle also increased with the decrease of the h value, especially when h 0.6 m, as well as F_h/h, though Q and V_o were almost constant regardless of the h value (Table 4). Therefore it is considered that differences in Δh may have been caused by the increase and the difference in the flow disturbance in each pool along with the decrease of the h value.



* Δ(Vxz) : Possible maximum fluctuation range of Vxz.
hu : Average depth of the head pool. hd : Average depth of the tail pool.

Fig. 7. Possible maximum fluctuation range of orifice velocity in the whole model (prototype size)

(3) The Δh value in Type 1 was larger than that in a normal submerged orifice for the same values of Q and h, presumably due to the interference of the pool flow disturbance with the orifice flow in Type 1. But the Δh value in Type 1 approached that in a normal submerged orifice with the increase of the h value. Both became almost identical when h 1.5 m. This also indicates that the pool flow disturbance decreased with the increase of the h value.

(4) The Δh value in an orifice at the upstream end (No.1 orifice) was almost identical with that in a normal submerged orifice regardless of the h value. Therefore it is considered that a normal submerged orifice flow was maintained in No.1 orifice provided that h ≧ 0.6 m.

(5) Q and V_o tended to increase slightly with the increase of the h value when h ≦ 1.0 ~ 1.5 m and to decrease slightly when h > 1.0 ~ 1.5 m (Table 4). This finding suggests that the orifice flow in Type 1 shifted to a normal submerged orifice flow when h 1.0 ~ 1.5 m, for which values the interference with the orifice flow decreased to some extent by the increase of the h value.

(6) In No.1 orifice, V_1 was close to V_2 and the values did not change appreciably in spite of the changes in the h value, in time series (Figs. 6 and 7), probably due to (4). In other orifices, the same phenomenon may occur with the increase of the h value due to (5). Namely, in all the orifices, V_1 is likely to decrease and V_2 to increase when the h value increases.

(7) Medium value of V_1 and V_2 in No.1 orifice was less than 1.2 m/s regardless of the h value (Fig. 6). This

finding in addition to (6) suggests that V_2 did not increase above 1.2 m/s in all the orifices in spite of the changes in the h values, provided that h ≧ 0.6 m.

(8) It is highly probable that when h ≧ 0.8 m in Type 1, the area with a low velocity around the rim of an orifice may become wider than that in the partial model (Fig. 5) for the following reasons: (i) The V_o value in Type 1 was close to the value (0.860 m/s) in the partial model (Table 4), though the sectional area of an orifice in Type 1 was wider than that in the partial model, and it is considered that the V_o value in Type 1 gradually decreases with the increase of the h value when h > 1.0 ~ 1.5 m based on (5); (ii) (V_1 in each orifice) ≧ (V_1 in No.1 orifice) in Type 1 based on (6) and (V_1 in No.1 orifice) ≧ (V_2 in the partial model (1.21 m/s)) based on Fig. 6 when h ≧ 0.6 m; (iii) The V_2 value in Type 1 did not exceed the V_2 value (1.21 m/s) in the partial model based on (7), though the V_2 value in Type 1 gradually increased from about 0.7 m/s when h ≧ 0.8 m based on Fig. 6 and (6).

(9) It is highly probable that in short span orifices like in Type 1, the area with a low velocity around the rim of an orifice becomes wider with the extension of the non-superimposed area of an orifice to the fixed superimposed area, because the superimposed area of an orifice in Type 1 was the same as that in Type 2, (Q in Type 1)   (Q in Type 2), (V_1 in Type 1)   (V_1 in Type 2) and (V_o in Type 1) < (V_o in Type 2).

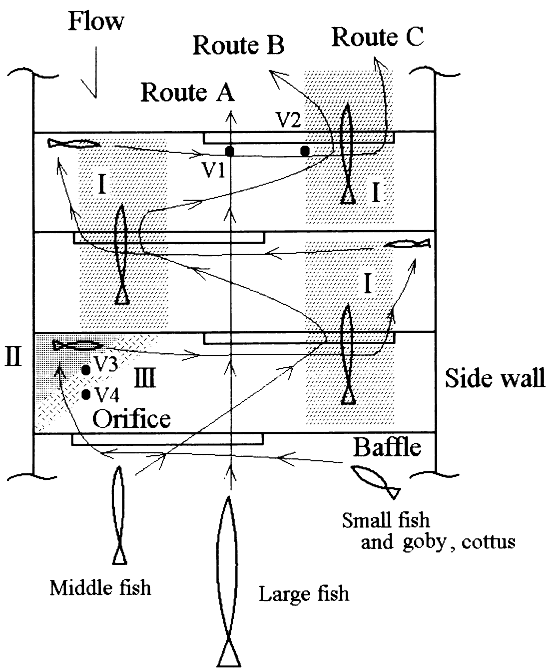


Fig. 9. Migration routes and rest areas (Type 1)

2. Performance in relation to the migration of various fish species

Table 5, Figs. 9 and 10, based on experimental results when h = 0.8 m, indicate that the fishes can migrate upstream through Type 1 fishway except for fish larger than about 0.9 m in length and middle-sized goby and cottus with a length of 0.06 ~ 0.17 m[10]. The same performance can be maintained when h ≧ 0.8 m since V_1 decreases, Q, V_o are almost the same and V_2 ≦ 1.21 m/s with the increase of the h value. But another fishway like

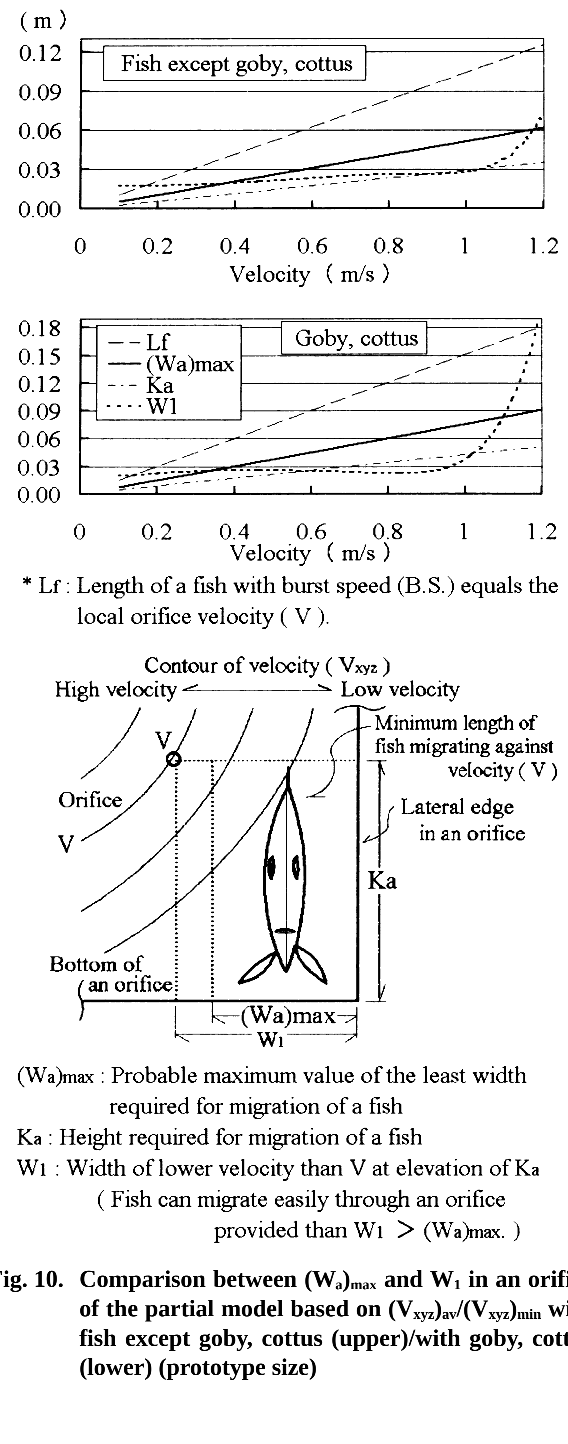


Fig. 10. Comparison between $(W_a)_{max}$ and W_1 in an orifice of the partial model based on $(V_{xyz})_{av}/(V_{xyz})_{min}$ with fish except goby, cottus (upper)/with goby, cottus (lower) (prototype size)

Table 5. Probability of fish migration through Type 1 fishway based on hybraulic experiment results for h = 0.8 m (prototype size)

Fish length (L_f)	Conditions for migration and rest in the fishway	Probability of migration and inference of migration routes
0.9 m ~	K_a > (Height of orifice)	It is difficult for these fish to migrate.
0.5 ~ 0.9 m	C.S. > $(V_1)_{max}$*1 $(W_a)_{max} > B_s$ = 0.15 m (Interval between linked pools) = 3.78 m (Fig.4)*2	Probable by route A without rest especially for relatively small fish*3 (Fig.9).
0.25 ~ 0.5 m	B.S. > $(V_1)_{max}$*1 $(W_a)_{max}$ < B = 0.475 m C.S. > $(V_2)_{av}$*1 ~ $(V_2)_{max}$*1 ≧ (Velocity in area I (Fig.9)) $(W_r)_{max}$ ≦ (Width of area I (Fig.9)) = 0.24 m	Probable by route B with rest in area I (Fig.9).*4
0.18 ~ 0.25 m	B.S. > $(V_2)_{max}$*1 ≧ (V_{max} in area I (Fig.9)) $(W_a)_{max}$ < (Width of area I (Fig.9)) = 0.24 m C.S. > $(V_2)_{av}$*1 ≧ (Average velocity in area I (Fig.9)) (Width for horizontal U-turn motion of a fish)*5 ≦ (Pool length) = 0.25 m	Probable by route C through area I section of an orifice with rest in area I or a pool (Fig.9).*6
0.125 ~ 0.18 m	B.S. > $(V_2)_{max}$*1 ≧ (V_{max} in area I (Fig.9)) $(W_a)_{max}$ < (Width of area I (Fig.9)) = 0.24 m C.S. ≧ V_3 ~ V_4*7 ≧ (Velocity in the lower part of area II ~ III)*8 K_r ≦ 0.052 m*9	Probable by route C through area I section of an orifice with rest in the lower part of area II ~ III (Fig.9).
~ 0.125 m	$(W_a)_{max}$ ≦ (W_1 near edge of an orifice) for fish less than 0.045 m in length in the partial model (Fig.10)*10 (W_1 in the partial model) < (W_1 in Type 1)*11	Probable by route C through area I section near the edge of an orifice with rest in the lower and corner part of area II ~ III (Fig.9). (∵ These small fish migrated through orifices in the past experiment results[13] with higher velocity and velocity fluctuations in an orifice, a pool. *12)
Goby, cottus (Maximum length : 0.3 m)		
0.17 ~ 0.3 m	B.S. $(V_2)_{max}$*1 ≧ (V_{max} in area I (Fig.9)) G.V. (Velocity in the lower and corner part of area II) ≦ V_3*8 K_r ≦ 0.086 m*9	Probable by route C through area I section of an orifice with rest in the lower and corner part of area II (Fig.9).
~ 0.17 m	$(W_a)_{max}$ ≦ (W_1 near edge of an orifice) for goby, cottus less than 0.06 m in length in the partial model (Fig.10)*10 (W_1 in the partial model) < (W_1 in Type 1)*11	Probable by route C through area I section near the edge of an orifice with rest in the lower and corner part of area II for goby, cottus less than 0.06 m length (Fig.9). (∵ These fish migrated through orifices in the past experiment results[13] with higher velocity and velocity fluctuations in an orifice, a pool. *12)

*1: $(V_1)_{max}$ ≦ 1.93 m/s, $(V_2)_{max}$ ≦ 1.21m/s, $(V_2)_{av}$ ≦ 0.71 m/s (Fig.6).
*2: The head and tail pools are linked pools when many fishways are connected.
*3: Because the swimming speed is higher than the flow velocity (then $W_a \ll (W_a)_{max}$) and migration distance between linked pools is short, though the swinging width of a caudal fin is limited by the superimposed width of adjacent orifices (B_s).
*4: Though the flow velocity in some of area I in the fishway may exceed C.S. of small fish, these fish can easily move into upstream area I since B.S. > $(V_1)_{max}$*1.
*5: Width for horizontal U-turn motion of a fish is less than fish length[3].
*6: Though the flow velocity in area I may sometimes exceed C.S. of these fish, they can easily move into the upstream pool and rest there since (velocity in a pool) < (velocity in area I section of an orifice), then they can move to the upstream orifice by horizontal U-turn motion in a pool.
*7: Average velocity of V_3 ~ V_4 was less than 0.4 ~ 0.6 m/s (Fig.8).
*8: Because the velocity in the lower part than the elevation of measurement points of V_3, V_4 does not exceed V_3, V_4 in areas II, III.
*9: K_r is less than the distance (0.125 m) between the elevation of measurement points of V_3, V_4 and the elevation of the pool bed (Fig.4).
*10: In Type 1, W_1 near the edge of an orifice can sometimes become wider due to the fluctuations of the orifice velocity, for example the V_x value at M2 sometimes became 0 m/s in Type 1.
*11: Because (V_2 in the partial model) > (V_2 in Type1 fishway (Type1)), (B of the partial model) < (B of Type1 fishway), (S_r of the partial model) > (S_r of Type1 fishway).
*12: In this experiment, goby and cottus with a length of 0.03 ~ 0.04 m and the other fishes with a length of 0.04~0.16 m migrated upstream through a pool and weir fishway (site scale model) provided that V_2 0.9 ~ 1.3 m/s, (Orifice height) = B = (Pool length) = 0.25 m, (Pool width) = 0.8 m, (Average overflow width) = 0.4 m, h ≦ 0.8 m, Q = 0.084 m^3/s. And more than 80% of these passed through orifices.[13]

a fish collection channel may be required for large fish. And also stone chips or brushes bonded to the orifice bottom may be required for migration assistance of middle-sized goby and cottus, though they can migrate when V_2 sometimes reaches 0 m/s.

3. Possibility of high drop and steep slope

Total value of the drop in Type 1 fishway is about 1.47 m and linkage of fishways is required for a higher drop. In this case, flow stabilization by the linked pools is necessary to maintain the flow state and fishway performance in a non-linked fishway. For flow stabilization, the linked pool volume must be sufficiently large. Pool length for this sufficient volume is considered to be less than 3 m, which corresponds to a pool length of "the pool and weir fishway"[5]. This is because, in this fishway pool, flow stabilization is adequately achieved provided that the velocity at the center of the orifice is 2.3 m/s, the orifice discharge is 0.09 m^3/s, the average overflow velocity is 1.15 m/s and the unit overflow discharge is 0.28 m^3/s/m[5,13], which is a more difficult condition for flow stabilization compared with the flow condition in the Type 1 fishway where $V_1 \leqq 2$ m/s, $Q \leqq 0.12$ m^3/s (Fig. 6, Table 4). Furthermore, a pool length less than 0.5 m can be obtained in the linked pools because the flow in the tail pool (No.14 pool) in these experiments was relatively stabilized. However, due to the short length, wider linked pools or pool bed blocks for the control of the acceleration of the orifice flow may be required. If the linked pool length is 0.5 ~ 3 m like above, the fishway slope is 1/2.84 ~ 1/4.54 even if the baffle thickness is 0.03 m. This slope is close to the downstream surface slope of rock fill dams and steeper than the slope of other fishways.

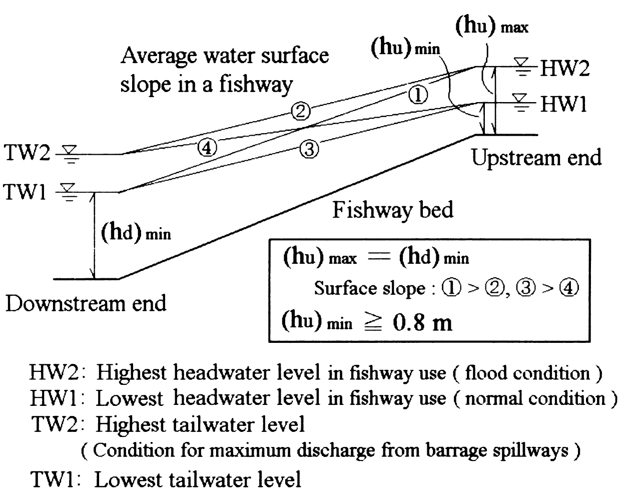


Fig. 11. Variation of average water surface slope in an orifice fishway (prototype size)

4. Discharge and stability of discharge, flow state in relation to changes in head or tailwater level

When the average slope of the water surface is less than or equal to 1/2.84 ~ 1/4.54, Type 1 fishway shows a low discharge (less than 0.12 m^3/s) provided that $h \geqq 0.6$ m (Table 4), and a high performance in the migration of various fish species provided that $h \geqq 0.8$ m. Accordingly, a lower average water surface slope than 1/2.84 ~ 1/4.54 and $h \geqq 0.8$ m are required for high performance in discharge saving and fish migration. This condition can always be maintained independently of the changes in the head or tailwater level if the fishway bed elevation at the upstream/ the downstream end is set as shown in Fig. 11 and the bed slope is set at a value less than or equal to 1/2.84 ~ 1/4.54.

5. Effect on prevention of excessive predation, blockage

Probability of excessive predation by birds is considered to be low because of the short baffle span (0.25 m) and short migration routes near the fishway bed. Also predation by carnivorous fish can be low because of flow disturbance to some extent and the narrow space in the pool. It is considered that a short baffle span is effective in preventing drifting materials from flowing into the fishway in case of flood when the fishway is submerged. And it is considered that the possibility of orifice closure by drifting sand or gravel is low because the approach velocity to the orifice is too low to enable gravel movement while the orifice flow velocity and pool flow fluctuations are sufficient for flushing inflow sand.

Conclusion

A new type of fishway with improved submerged orifices was proposed (Fig. 4). The effects of the use of this fishway are as follows: (1) Various fish species can migrate through the fishway when $h \geqq 0.8$ m except for fish larger than about 0.9 m in length; (2) The fishway can be set on a steep slope of 1/2.84 ~ 1/4.54; (3) It can be used with a low discharge of less than 0.12 m^3/s; (4) It can be used independently of changes in head or tailwater level if the fishway bed elevation at the upstream/ the downstream end is set as shown in Fig. 11 and the bed slope is set at a value less than or equal to 1/2.84 ~ 1/4.54; (5) It can prevent excessive predation by birds, carnivorous fish due to the short and low migration routes through this fishway, narrow space between baffles and flow fluctuations in the pools; (6) It can prevent excessive blockage by drifting materials, sand or gravel due to the short span between baffles, submerged orifice inlet and flow fluctuations in the pools.

Further studies are required for minimizing the linked pool volume, especially in case of many linkages.

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