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Pool-type fishway on the Sembayat barrage

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Abstract. This paper presents the hydraulic flow system in a fishway to simulate the flow of a pool-type fishway. A fishway is a waterway to allow some fish species to pass by a human-made obstruction in a river or stream. The construction on the river, which has no fishway, will impact the river ecosystem balance. The purpose of this research is to give an alternative to reduce negative effect on the river ecosystem because of the obstruction. The velocimeter and the flow type in fishway must be able to be passed by the fish. In a kind of the pool-type fishway, there is an orifice in the bottom that has a potential supercritical flow before it becomes subcritical flow. The purpose of this experiment is to identify the surge in the pools of the fishway. The physical model of the pool-type fishway in Sembayat Barrage, Gresik was created to analyse the hydraulic condition of the flow in the fishway structure. The velocity has a greater value than the permissible velocity of the fish, and thus several fishways are not able to function optimally because the fish refuse to swim through the fishway. From the results of the study, it can be concluded that the velocity can be reduced by adding baffles at the downstream part of the orifice.

Keywords: fishway, pool-type, orifice, velocity

1. INTRODUCTION

The life cycle of fish that often migrate from upstream to downstream can be disrupted by the construction of dams, and thus a fishway is needed to maintain the fish population. A fishway is a waterway to allow some fish species to pass by a man-made obstruction in a river or stream. The construction on the river, which has no fishway, will impact the river ecosystem balance because the fish have a migration character from downstream to upstream. The primary function of a fishway is to provide passage over hydraulic barriers to fish swimming upstream. A number of fishway designs are commonly used across the world and are placed under two broad categories: engineered structures and nature-like fishways. Engineered structures are built with “hard” construction materials (such as steel or reinforced concrete) and include the pool-and-weir, Denil, and vertical slot designs. Nature-like fishways are constructed using natural or so-called “soft” materials (such as boulders, gravel, and logs) and are designed to mimic the hydraulic, bed, and bank conditions of a natural stream [6]. In Indonesia, fishways have not been applied yet in every man-made river obstruction. One of the more common types of fishway designs is the pool-type fishway, which consists of several pools as places for fish to rest or migrate. An eco-hydraulic river system with fishway structure had been applied to several dams in Indonesia, such as Perjaya Dam in Ogan Komering Ulu in South Sumatera, Batang Hari Dam in West Sumatera, and Wawatobi Dam in South Sulawesi [5].

The success of a fishway can be determined by the period of fish swimming through the fishway. The velocity in a fishway must be less than that of the speed-swimming ability of fish, because the hydraulics of a fishway affect its function. Generally, fishways are divided into two kinds: nature-like fishways and technical fishways (of the pool, slot, Denil, eel ladder, and lock types) [4]. The purpose of this research is to find out the flow pattern in a pool-type fishway based on the planned scale dimensions. The observation for the flow pattern is performed by making a grid based on the distance and water depth in the pools.



1.1. Pool-Type Fishway

The principle of this type is to divide the water level into stages by using walls. Pool-type fishways are usually designed straight from upstream to downstream. A variety of barrier structures may be used in a pool-type fishway, including cross wall, rhomboid, and humped fish. With a cross wall, the water only flows through the upper and lower holes [5].

A smaller head difference (or drop, DH) between two pools makes it easier for fish to pass. However, this head difference cannot be reduced too greatly because the number of pools required would then become prohibitive [2]

The maximum velocity of the flow created by the drop DH can be approximated by $V = (2g DH)^{0.5}$, where g is the acceleration due to gravity (9.81 m/s^2). Head differences between pools of 0.15 m, 0.30 m, and 0.45 m, correspond to maximum flow velocities of approximately 1.7 m/s, 2.4 m/s and 3.0 m/s respectively. The drops between the pools are selected primarily as the function of the swimming or leaping capacities of the species concerned (Figure 1).

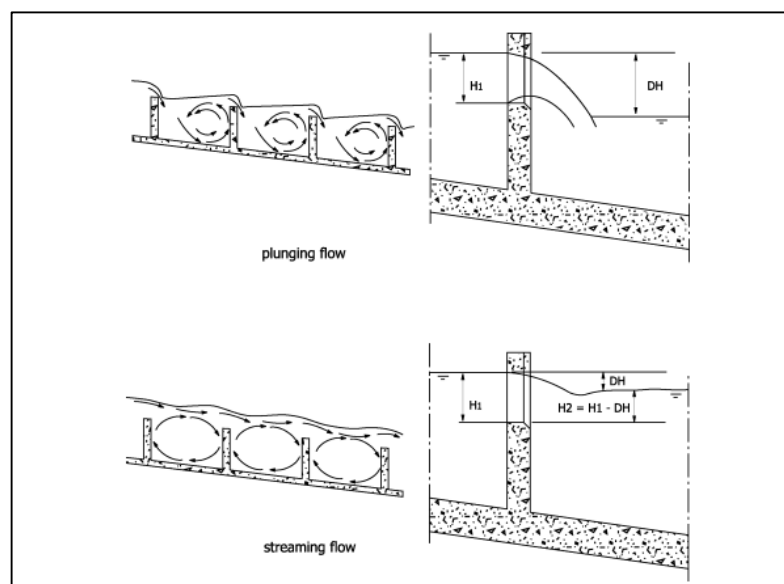


Figure 1. Plugging and streaming in a fishway [4]

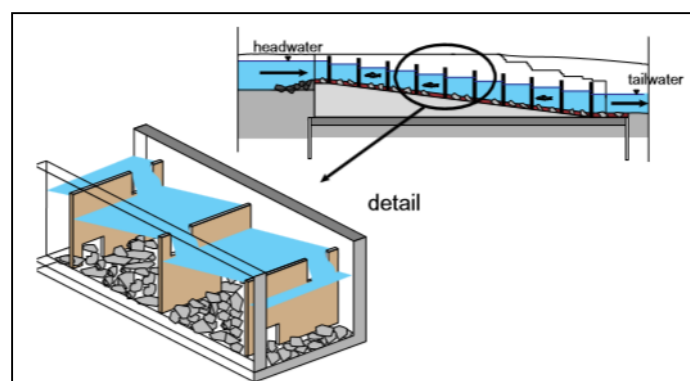


Figure 2. Pool-type fishway with cross walls [4]

1.2. Flow through Orifices

Fishway discharge for orifice flow may be analysed as

- a vertical slot for $y_o < z_o$
- a submerged jet for $y_o > 2z_o$
- an unsubmerged jet in-between depths where the orifice is submerged only on the upstream side.

A pool-type fishway has two orifices (Figure 2). One hole is on the bottom of the wall and submerged by water, and the other is on the top of the wall. The orifice is rectangular in shape. The flow that comes out

through the orifice may have several types of energy (low, high, or constant) depending on the type of discharge, whether steady or unsteady flow. Flow through the orifice or hole is divided into two types: submerged flow and free flow. Flow parameters in the orifice include the coefficient of contraction, discharge, and velocity. These parameters will experience energy loss with flow through the orifice.

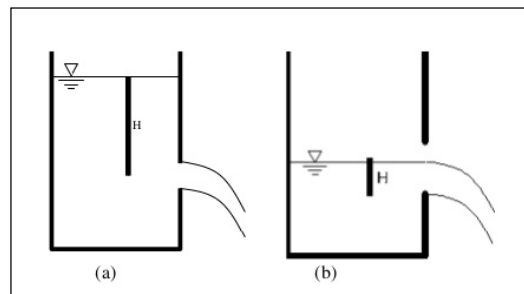


Figure 3. (a) Orifice with submerged flow, (b) Orifice with free flow [3]

In a submerged orifice, the water level downstream of the hole has a higher elevation than the water flowing out of the hole (Figure 3). Thus, the equation of flow and discharge velocity for the submerged hole is based on the Bernoulli formula [3] below:

$$Z_1 \frac{\rho_1}{\gamma} + \frac{v_1^2}{2g} = Z_2 \frac{\rho_2}{\gamma} + \frac{v_2^2}{2g} \quad (1)$$

Then, the values of flow velocity and discharge can be calculated with the formula below:

$$v = \sqrt{2g(H_1 - H_2)} \quad (2)$$

Because the flow to the orifice has a speed value, the smooth flow can be calculated with the following formula:

$$Q = \frac{2}{3} C_d b \sqrt{2g \left\{ \left(H_2 + \frac{v_0^2}{2g} \right)^{3/2} - \left(H_1 + \frac{v_0^2}{2g} \right)^{3/2} \right\}} \quad (3)$$

Where v is velocity, Q is the discharge of the fishway, C_d is the discharge coefficient, b is orifice width, g is gravitational acceleration, H_2 is the difference in water level with the base of the orifice, and H_1 is the difference in water level with the top of the orifice.

2. MATERIALS AND METHODS

The aim of the fishway model is to evaluate the condition of hydraulic design to control maximum velocity. The model is an undistorted model with scale of 1 to 3.75. Experiments were conducted at the Hydraulic and Coastal Engineering Laboratory of the Civil Engineering Department, Sepuluh Nopember Institute of Technology, Surabaya. Some characteristic operation conditions of the pool-type fishway were analysed in the model. The water levels and the mean velocities in various points of the flow were measured with a ruler and Acoustic Doppler Velocimeter (ADV). These parameters and visual observations of the pool-type fishway were used to evaluate the performance of the permissible velocity in various test conditions. The discharge to the model was totally controlled by the laboratory supply system. The capacity of the laboratory diesel pump is approximately 10 l/sec for the experiment. The rating curve of the discharge on the model is presented in Figure 4 below.

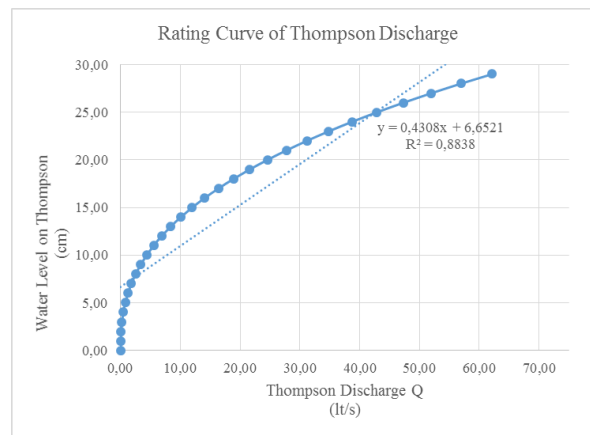


Figure 4. Rating curve of Thompson discharge

The fishway is composed of three main parts with a total model length of 5 m and 0.167 slope: (i) an upstream resting pool; (ii) passage pools, composed of 10 pools with a pool length of 33 cm for model; and (iii) a downstream resting pool. The pools are connected by slots with heights of 27-36 cm and a width of 0.33 cm. This is designed to allow passage of local fish such as local catfish (*jambal*, *tagih*), milkfish, and tilapia. The fishway cross-section and condition are presented in Figures 5-6 below.

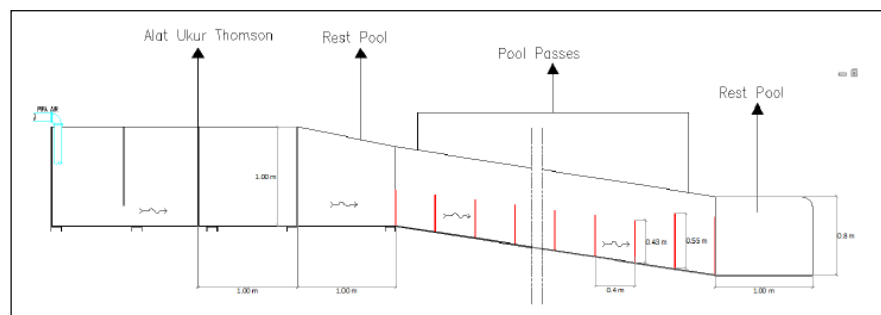


Figure 5. Cross section of the fishway



Upstream resting pool

Downstream resting pool

Figure 6. Fishway condition in the laboratory

Discharge calibration was carried out using a Thompson measurement in the upstream part and a measuring cup in the downstream part. From the results of the analysis of discharge using the Thompson measuring instrument, the amount of release was compared with the theoretical Thompson discharge calculation. The calibration results are shown in Figure 7 below.

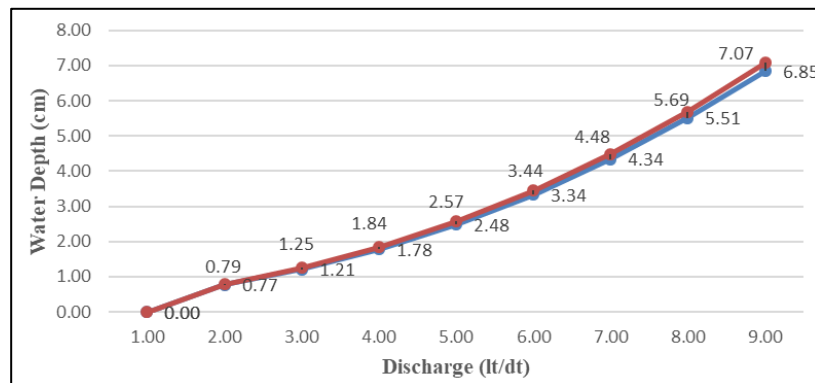


Figure 7. Thompson calibration vs. cup measurement

3. RESULTS AND DISCUSSION

Measurement of water depth in the fishway was performed using Thompson discharge variations of 4.48 l/sec, 5.69 l/sec, and 7.07 l/sec. For the Thompson discharge of 7.07 l/sec, the water depth in the pool reached the maximum limit, and for the discharge of 4.48 l/sec, the water level in the pool met the minimum threshold. A wall with a height of 22 cm was used to determine the boundary of downstream conditions. The cross-section of the fishway is shown in Figure 8.

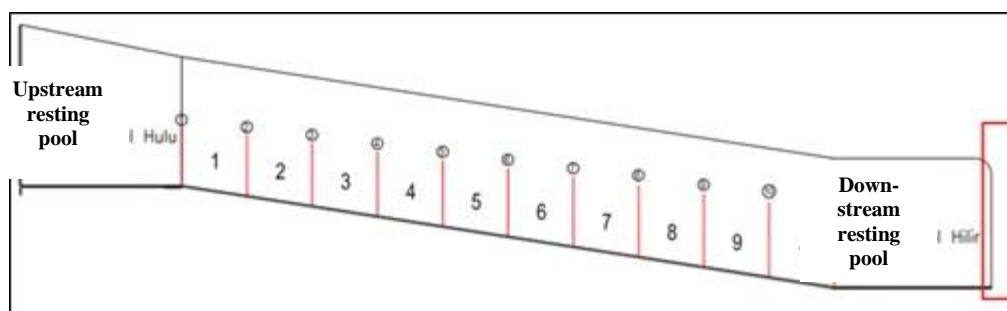


Figure 8. Cross section of the fishway

The 22 cm downstream resting pool wall is the dimension of the fishway design to create water depth in the downstream resting pool according to calculations. The water depth at the downstream resting pool with a 22 cm wall with the Thompson discharge of 7.07 l/sec is 44.5 cm, with the discharge of 5.69 l/sec is 44 cm, and with the discharge of 4.48 l/sec is 43 cm.

The modelled water depth showed closeness to the water depth of the physical model. The most significant difference in the water depth between walls was an average of 3 cm, located from passage pool 1 to the end of the pools. Since step heights of up to 0.5 cm are considered satisfactory for the journey of the fish species, the water profile can be regarded as adequate for their passage. The highest velocity was found for pool 5, with an average velocity of 0.48-0.95 m/s. The conclusion is that pool 5 is satisfactory for fish migration. The assumed difference between upstream and downstream resting pool water depth is less than 2.5 cm in the model. The minimum flow to be adopted in the fishway should be approximately equal to 0.12 m³/s.

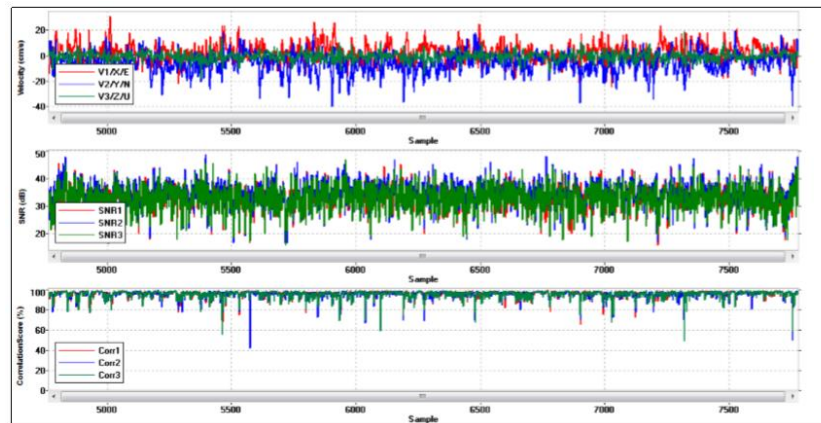


Figure 9. Data reading with the Acoustic Doppler Velocimeter (ADV)

Based on the Froude number of 0.07 and Reynold number of 11293.47, subcritical turbulence occurred in the pool according to Robertson and Rouse [1]. A turbulent flow that occurs in fishway ponds due to differences in the depth of water between the pools and the flowing water is blocked by the fishway wall before finally flowing through the upper and lower orifices. From the measurement results obtained for the model, the velocities for each discharge are (Q) 4.48 l/sec, $V = 0.89$ m/sec; (Q) 5.69 l/sec, $V = 1.17$ m/sec; and (Q) 7.07 l/sec, $V = 1.25$ m/sec (Figure 9).

Based on the prototype design, the dimension of the orifice is 0.3 m. The velocity in the prototype was calculated with the modelled velocity. The calculation for the velocity scale nu used the following equations:

- H model orifice = 0.06 m
- H prototype orifice = 0.3 m
- $nh = H_p / H_m = 0.3 / 0.06 = 5$
- $nt = nh^{1/2} = 5^{1/2} = 2.236$
- $nu = nh \cdot nt = 5 \cdot 2.236 = 2.24$

The velocity of the prototype condition with discharge Q 4.48 l/sec is

- $nu = 2.24$
- $V_m = 0.89$ m/sec
- $V_p = nu \times V_m = 2.24 \times 0.89 = 1.99$ m/sec.

The orifice on the pool-type fishway is the main factor for attracting fish to be able to swim through the fishway. Thus, the flow velocity in the orifice must be below the ability of the fish to swim. The flow velocity of the pool-type fishway is to be able to be adopted by various types of fish that swim < 1.2 m/sec. From the experimental results, it was concluded that the velocity on the pool is greater than the permissible velocity.

The second model in this experiment was created by adding baffles in a pool. Baffles were placed at the downstream of the lower orifice, which drains discharge from the previous pool. In addition, the baffles were designed to reduce the velocity of incoming flow through the lower orifice that flows into the downstream wall before heading to the next orifice. The utilized baffles have a width of 0.03 m, and the height is 0.3 m. The following is the measurement scheme for baffle placement in the pool (Figure 10).

Reduction of velocity was achieved by adding the baffles downstream of the orifice. From the measurement results, the velocities on the model for each discharge are (Q) 4.48 l/sec, $V = 0.44$ m/sec; (Q) 5.69 l/sec, $V = 0.63$ m/sec; and (Q) 7.07 l/sec, $V = 0.70$ m/sec.

The calculation for the velocity condition with 4.48 l/sec discharge is

- $nu = 2.24$
- $V_m = 0.44$ m/sec
- $V_p = nu \times V_m = 2.24 \times 0.44 = 0.99$ m/sec, thus the velocity in the pool by adding baffles is 0.99 m/sec in the prototype condition.

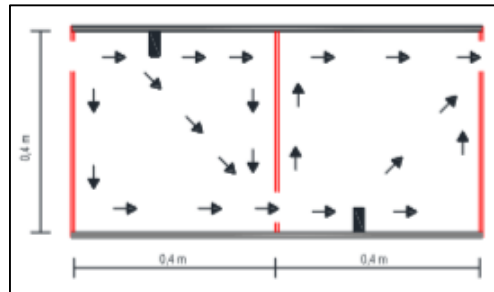


Figure 10. Baffle placement on fishway pool

4. CONCLUSION

The modelled water depth showed closeness to the water depth of the physical model. The greatest difference of the water depth between neighbouring pools is an average 3 cm, located from passage of pool 1 to the end of pools. As step heights of up to 0.5 cm are considered satisfactory for the passage of the fish species, the water profile can be considered adequate for their passage. The highest velocity was found for pool 5 with an average velocity of 0.44-0.95 m/s. The conclusion is that pool 5 is satisfactory for fish migration.

REFERENCES

- [1] Chow, Ven Te. 1992. *Hidraulika Saluran Terbuka [Hydraulics of Open Channels]*. Erlangga, Surabaya.
- [2] Katopodis, Chris P.Eng. 1992. *Introduction To Fishway Design*. Canada: Freshwater Institute.
- [3] Triatmodjo, Bambang. 1993. *Hidraulika I [Hydraulics I]*. Beta Offset. Yogyakarta
- [4] Anonymous. 2002. *Fish Passes- Design, Dimensions, and Monitoring*. Terj. FAO (Food and Agriculture Organization of The United Nations). Rome: DVWK (Deutscher Verband für Wasserwirtschaft und Kulturbau e.V.).
- [5] Maryono, Agus. 2008. *Rekayasa Fishway (Tangga Ikan) [Fishway (Fish Ladder) Engineering]*. UGM Press, Yogyakarta.
- [6] Marriner, Bryan A, et al. 2016. The hydraulics of a vertical slot fishway: A case study on the multi-species Vianney-Legendre fishway in Quebec, Canada. *Ecological Engineering* 90 (2016) 190–202 www.elsevier.com/locate/ecoleng.