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A case study for optimal position of fishway at low-head obstructions in tributaries of Han River in Korea

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ABSTRACT

The biggest problem involved in installing fishways at obstacles across natural streams is to engineer the optimal position of the fishway entrance. The four criteria that were used in this study to construct a fishway at low-head submerged weirs located in the Han River of Korea are established based on previous studies. The criteria include, the farthest point toward upstream, the vicinity of the thalweg, the vicinity of the primary velocity, and a point of less erosion and deposition. Among these, the third and fourth criteria are revealed by means of flow and sediment transport analysis. In particular, the entrance and exit of a fishway have often been closed due to the action of erosion and deposition resulting from extreme flood events that occur in the monsoon season of Korea. Numerical models of two-dimensional flow and sediment transport are used to reveal the structure of the flow field and characteristics of erosion and deposition. The propriety of location of the fishway is verified based on the four criteria using the numerical simulation at the Gapyeng Stream, which has many fishways. The efficiency of the fishway is evaluated indirectly by monitoring the fish. The criteria are also used to locate the best position of a fishway at a weir located in the Wangsuk Stream, which is a tributary of the Han River and does not have any fishway.

1. Introduction

Many different types of devices have been used to facilitate migration of fish past obstructions on watercourses. Such a type of fish facility is generally known as a fishway, fish ladder, or fish pass. Regardless of what they may be called, all fishways have the same definition. They are essentially a water passage around or through an obstruction, designed to dissipate the energy in the water in such a manner as to enable fish to ascend without undue stress (Clay, 1995). Fishways must be designed and located based on the hydraulic characteristics and behavior patterns of the migrating species. When appropriately designed and situated, fishway structures allow upstream migrating fishes to bypass river barriers to reach river segments suitable for growth and reproduction (Clay, 1995; Jungwirth et al., 1998). Over the last century, developing fishways have targeted high-value migrant adult salmon in both North America and Europe. In more recent years, efforts have turned to developing fishways for others such as potamodromous species and various sizes of fish (Katopodis et al., 1991; Moser et al., 2002; Katopodis, 2005; Mallen-Cooper and Brand, 2007; Tarrade et al., 2008; Silva et al., 2010).

There are numerous obstructions such as weir, barrier, and dam made by concrete structures in the Han River watershed located in Korea. Low-head fixed weirs, which are 0.5–3.0 m high and get submerged except during low water season, have been broadly installed at the tributaries of the Han River in order to raise the water level for agricultural use as shown in Fig. 1a. These streams are mainly inhabited by potamodromous fish, but the obstructions have prevented the fish from moving upstream and downstream, which has caused a reduction in its life-cycle, often eliminating the fish species. Recently, to mitigate these negative effects, a number of fishways are being constructed at the weirs (Fig. 1b).

Site-specific design variations in fishways related to slope, width, length, depth, configuration (i.e. shape, design and number of pools, traverses, orifices, baffles or roughness elements), entrance location and other factors also influence the effectiveness of attraction and passage for different fish species (Bunt et al., 2012). Among those, the biggest problem that we face when we plan to install a fishway at obstructions is how to best position the fishway entrance in this situation. The attraction efficiency of a fishway is the important issue because the most fixed weirs in tributaries of Han River have no adjustable gates or anything similar and

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(a) Low-head concreted fixed weir

(b) Fishways installed at Dangmugae weir in Gapyeng stream

Fig. 1. Low-head fixed weirs and fishways.

provides no attraction flow. In here, the efficiency of a fishway may be classified into two categories, the attraction and passage efficiency. Lucas and Baras (2001) have pointed out that two principal components of the effectiveness of a fish pass are its ability to attract fish to the entrance, and the ability of fishes which have located the entrance to successfully pass though the fishway, termed attraction and passage efficiency respectively.

To find out the optimal location for a fishway, it is necessary to understand the hydraulic characteristics of the surrounding fishways. Hydraulics in fish passage structures have been investigated for more than 20 years. Most numerical simulations have focused on the flow field inside a fishway according to its type. For example, Barton and Keller (2003), Cheong et al. (2006), Cea et al. (2007), Heimerl et al. (2008), Bermudez et al. (2010), and Kim et al. (2012) have used two or three-dimensional models to visualize the flow structures in the interiors of the pool-type fishways that was widely found in North America. Their results may be helpful in designing pools and providing a detailed and close-to-reality picture of the flow within a fishway. However, it is surprising to find that there is lesser published research on numerical simulation of flow fields around fishways than those inside.

In this study, we focused on fishway attraction efficiency rather than passage efficiency inside fishways, under the macro view of hydrodynamics. This was conducted by analyzing how to best position the fishway entrance at low-head submerged weirs without any adjustable gates installed at medium or small-scale streams, which is the tributaries of the Han River in Korea. Above all, the four major criteria to be taken into consideration to install a fishway at fixed weirs were established based on previous studies. Then the location of fishways constructed at Gapyeng Stream tributary of the Han River was evaluated based on these criteria. To apply the criteria to the object streams, numerical analysis was conducted two-dimensionally to simulate flow field and sediment transport. The efficiency of the fishway was also validated indirectly by monitoring the fish.

2. Methodology

2.1. The criteria: how to best position fishway at obstructions

The best way to decide on the location of the fishway is to construct more than one fishway at a weir. The fishes can migrate upstream through the other fishways even if one of them is not able to perform its function. When only a single fishway is installed at a weir, for economic reasons, the four criteria proposed in this study based on previous studies should be considered.

There are many studies on the criteria or principles for designing and constructing fishways. However, these criteria are suitable for applying to large dams with attraction flow located in large rivers. Recently, Baumann and Stevanella (2011) suggested the general fish passage principles to be considered for large dams at the tropical Mekong River, in Laos. The criteria proposed in this study are confined to special situations such as a low-head submerged weir without gates installed at medium to small-scale streams with active alluvial process as shown in Fig. 1. The four criteria are as follows:

(i) *Farthest point toward upstream*: The weirs are usually constructed perpendicular to the direction of the main channel. However, the oblique weirs across the channel also exist in meandering reaches. When the migrating fish meet the oblique obstacles, they move upstream and then gather together as shown in Fig. 2 (Cowx and Welcomme, 1998; Williams et al., 2011). It would be efficient to install fishways in fish gathering regions.

(ii) *Point near the thalweg*: Field survey has revealed that the biggest problem of having fishways installed at natural streams in Korea was that there was no water in the fishways during low flow condition (Gyeonggi Research Institute, 2008). The thalweg is a line drawn to join the lowest points along the entire length of a streambed, so flow occurs along the thalweg in the low water season. It is proper to install the fishway at areas near the thalweg.

(iii) *Point near the filament of primary velocity*: It is well known that migrating fishes swim upstream against the primary flow of the channel (Clay, 1995; Karppinen et al., 2002; Lundqvist et al., 2008). Thus, a fishway must be installed at an area near the filament of the primary flow.

(iv) *Point of less erosion and deposition*: The entrance and exit of a fishway are often closed by the action of erosion and deposition resulting from extreme floods that occur in the monsoon season in Korea. The location of the fishway entrance should avoid regions of active erosion because the erosion separates the entrance from the river bed. And the fishway exit should