available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/ecoleng

An optimal shape problem related to the realistic design of river fishways

L.J. Alvarez-Vázquez[a,*], *A. Martínez*[a], *M.E. Vázquez-Méndez*[b], *M.A. Vilar*[b]

[a] *Departamento de Matemática Aplicada II, ETSI Telecomunicación, Universidad de Vigo, 36310 Vigo, Spain*
[b] *Departamento de Matemática Aplicada, Escola Politécnica Superior, Universidad de Santiago de Compostela, 27002 Lugo, Spain*

ARTICLE INFO

Article history:
Received 16 February 2007
Received in revised form
25 September 2007
Accepted 12 October 2007

Keywords:
Fishway
River
Optimal shape design
Shallow water

ABSTRACT

A river fishway is a hydraulic structure that facilitates fish in overcoming obstacles (dams, waterfalls, etc.) to their spawning and other migrations in rivers. In this work we present a mathematical formulation of an optimal design problem for a vertical slot fishway, where the state system is given by the 2D shallow water equations fixing the height and velocity of water, the design variables are the geometry of the slots, and the objective function is determined by the existence of rest areas for fish and of a water velocity suitable for fish swimming capability. We also derive an expression for the gradient of the objective function *via* the adjoint system. From the numerical point of view, we present a characteristic-Galerkin method for solving the shallow water equations, and a direct search algorithm for the computation of the optimal design variables. Finally, we give numerical results obtained for a standard ten pools channel.

© 2007 Elsevier B.V. All rights reserved.

1. Introduction

The importance of preserving and enhancing natural stocks of diadromous and resident fish – salmon (*salmo salar*), trout (*s* almo trutta), eel (*anguilla anguilla*), sturgeon (*a* cipenser sturio), lamprey (*lampetra fluviatilis*, *petromyzon marinus*), barbel (*barbus bocagei*), carp (*cyprimus carpio*), perch (*perca fluviatilis*), etc. – has been recognized for at least the last 50 years. Diadromous fish are fish that migrate between freshwater and saltwater. Their migration patterns differ for each species: some diadromous fish migrate great distances, while others migrate much shorter ones. In both cases, fish undergo deep physiological changes that allow them to survive in their migrations. There exist three types of diadromous fish, depending on their specific migration patterns: anadromous, catadromous and amphidromous: Anadromous fish spend most of their adult lives in saltwater, and migrate to freshwater rivers and lakes to reproduce. Anadromous fish species include lamprey, sturgeon, salmon, and trout. More than half of all diadromous fish in the world are anadromous. Catadromous fish spend most of their adult lives in freshwater, and migrate to saltwater to spawn. Juvenile fish migrate back upstream where they stay until maturing into adults, at which time the cycle starts again. One of the main catadromous species is the eel. About one quarter of all diadromous fish are catadromous. Finally, amphidromous species move between estuaries and coastal rivers and streams, usually associated with the search for food or refuge rather than the need to reproduce. Amphidromous fish can spawn in either freshwater or in a marine environment. Less than one fifth of all diadromous fish are amphidromous.

Fishways are hydraulic structures that enable fish to overcome obstructions (for instance, dams or falls) to their

* Corresponding author. Tel.: +34 986 812166; fax: +34 986 812116.
E-mail addresses: lino@dma.uvigo.es (L.J. Alvarez-Vázquez), aurea@dma.uvigo.es (A. Martínez), ernesto@lugo.usc.es (M.E. Vázquez-Méndez), miguel@lugo.usc.es (M.A. Vilar).
0925-8574/$ – see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.ecoleng.2007.10.008

Nomenclature

- a, b design variables corresponding to the end points of the baffles (m)
- g acceleration due to gravity ($\mathrm{m\,s^{-2}}$)
- H height of water (m)
- $\vec{Q}$ areal flow per unit depth ($\mathrm{m^2\,s^{-1}}$)
- r half width of the baffles (m)
- u down stream velocity of water ($\mathrm{m\,s^{-1}}$)
- $\vec{u} = (u, v)$ vertically averaged velocity of water ($\mathrm{m\,s^{-1}}$)
- v cross stream velocity of water ($\mathrm{m\,s^{-1}}$)
- $\vec{v}$ target velocity of water for objective function j ($\mathrm{m\,s^{-1}}$)

Greek letter

- η bottom geometry of the fishway (m)

spawning and other river migrations, and are built whenever they are required, based on ecological, economical, or legal considerations. Fishways (also known as fish-ladders or fish-passes) are generally studied under three classes: the pool and weir type (Clay, 1995), the Denil type (Katopodis et al., 1997), and the vertical slot type (Rajaratnam et al., 1986). In addition to these three types, which enable the fish to swim upstream under their own effort, there is a more recent forth class: the fish-locks or fish-elevators, which lift the fish over the obstruction.

Pool and weir fishways were the earliest type constructed – the first recorded attempts to construct this type of fishway were made in Europe in the 17th century – and are still built with the addition of orifices in their walls. A pool and weir fishway consists of a number of pools formed by a series of weirs. The fish passes over a weir by swimming at burst speed (or in some cases salmon, trout, etc. by jumping over it). The fish then rests in the pool, then passes over the next weir, and so on, till it completes the ascent. The success of this type of fishway depends on the maintenance of water levels, which can be facilitated by the provision of a set of orifices in the weir walls close to the floor. The Denil fishway is essentially a straight rectangular flume provided with closely spaced baffles or vanes on the bottom and sides. The first of the classical works of G. Denil on the scientific design of fish-passes was already published in 1909 in A nnales des Travaux Publiques de Belgique. Of the many types of Denil fishway studied in the scientific literature, the more commonly used are the simple Denil fishway and the more complex “Alaska Steep-pass”.

However, we deal here with the third type of fishway, that is the more generally adopted for upstream passage of fish in streams obstructions: the vertical slot fishway. It consists of a rectangular channel with a sloping floor that is divided into a number of pools. Water runs downstream in this channel, through a series of vertical slots from one pool to the next one below. The water flow forms a jet at the slot, and the energy is dissipated by mixing in the pool. The fish ascends, using its burst speed, to get past the slot, then it rests in the pool till the next slot is tried (Blake, 1983). Thus, a fishway can be considered as a water passage around or through an obstruction, so designed as to dissipate the energy in the water in such a manner as to enable the fish to ascend without undue stress.

Our main aim consists of finding the optimal shape design of the vertical slot fishway so that the higher number of fish can ascend through the obstacle in the river in their best conditions.

In this paper we first introduce a mathematical formulation of the optimal design problem for a standard ten pools channel, where the state system is given by the shallow water equations determining the height of water and its velocity (averaged in height), the design variables are the geometry of the slots, and the objective function is related to the existence of rest areas for fish and a water velocity suitable for fish leaping and swimming capabilities. We also obtain an expression for the gradient of the objective function *via* the adjoint system. From the numerical point of view, we present a characteristic-Galerkin method for solving the 2D shallow water (Saint Venant) equations, and we propose a derivative-free algorithm for the computation of the optimal design variables. Finally, we present numerical results obtained for the ten pools channel under study.

2. Mathematical formulation of the problem

We consider a fishway $\omega \subset \mathbb{R}^2$ consisting of a rectangular channel with sloping floor that is 0.97 m in width. We assume that it is divided into ten pools, each pool having a length of 1.213 m. We also consider two transition pools, one at the beginning and other at the end of the channel, with flat floor, the same width, and a length of 1.5 m. The baffles that must be built in each pool have a width of $2r = 0.061$ m and are vertical to the flume bed slope that ranges from 2% to 20%. The fishway’s ground plan is schematized in Fig. 1: water enters by the left side and runs downstream to the right side, and fish ascend in the opposite direction.

Water flow in the channel along the time interval $(0, T)$ is governed by the shallow water (Saint Venant) equations:

$$\left.\begin{aligned} &\frac{\partial H}{\partial t} + \vec{\nabla}.\vec{Q} = 0 && \text{in } \omega \times (0, T) \\ &\frac{\partial \vec{Q}}{\partial t} + \vec{\nabla}.\left(\frac{\vec{Q}}{H} \otimes \vec{Q}\right) + gH\vec{\nabla}(H - \eta) = \vec{f} && \text{in } \omega \times (0, T) \end{aligned}\right\} \quad (1)$$

where $H(x, y, t)$ is the height of water at point $(x, y) \in \omega$ at time $t \in (0, T)$, $\vec{u}(x, y, t) = (u, v)$ the averaged horizontal velocity of water, $\vec{Q}(x, y, t) = \vec{u}H$ the areal flow per unit depth, g is the gravity acceleration, $\eta(x, y)$ represents the bottom geometry of the fishway, and the second member $\vec{f}$ collects all the effects of bottom friction, atmospheric pressure and so on. These equations must be completed with a set of initial and boundary conditions. In order to do that, we need to define three different parts in the boundary of ω: the lateral boundary

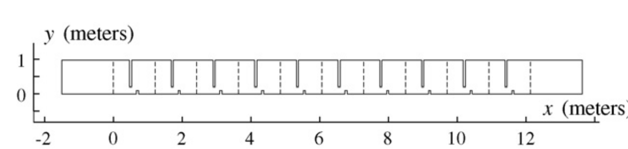

Fig. 1 – Ground plan of the ten pools fishway ω.

Download English Version:

https://daneshyari.com/en/article/4391050

Download Persian Version:

https://daneshyari.com/article/4391050

Daneshyari.com