Experimental and numerical investigation of a meandering jet in shallow rectangular reservoirs under different hydraulic conditions

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Abstract

A central meandering jet in shallow rectangular reservoirs has been investigated numerically by the model WOLF2D, on the basis of experimental evidence of this type of flow field in two different setups at different scales. The oscillation frequency of transversal velocity and the characteristic Strouhal numbers have been calculated for different Froude numbers. A sensitivity analysis has been conducted with respect to the main parameters of the model and a logarithmic relationship between the Strouhal and the Froude number has been found.

1. Introduction

In the framework of an experimental and numerical investigation of the different types of flow field that develop in a shallow rectangular reservoir subjected to different geometrical and hydraulic conditions (Kantoush, 2008; Dufresne et al., 2010; Camnasio et al., 2011), a central meandering flow pattern, characterized by periodic oscillation of velocity was found, for specific ranges of Froude, Reynolds number, and non-dimensional depths. In particular, the existence of meandering flow patterns was experimentally assessed in two different experimental rectangular reservoirs at different scales, having a length-to-width ratio L/B = 1.5 and an expansion ratio B/b = 16, where L is the length of the reservoir, B is its width and b is the width of the inlet free-surface channel. The first reservoir, at Ecole Polytechnique Federale de Lausanne, has dimensions L = 6 m and B = 4 m, b = 0.25 m. Kantoush (2008) had performed experiments on this reservoir with a constant discharge Q = 7 l/s, varying the water depth (h = 0.2 – 0.15 – 0.1 – 0.075 m) and so varying the non-dimensional depth h/b and the inlet Froude number $Fr_{in} = Q/b/h/(g*h)^{\wedge}0.5$. The Reynolds number of the experiments is $Re = 4*Q/b/\nu$ = 112000. Kantoush had assessed from a qualitative point of view the formation of a central meandering flow pattern when water depth was reduced at 0.15 m or lower. Anyway, in his work Kantoush hadn't carried out a study about the oscillation frequency of the jet nor about other quantitative characteristics of the phenomenon. The second facility is a reservoir at Politecnico of Milano, having L = 1,17 m, B = 0.78 m, b = 0.048 m which represents an approximately 1:5 scale model of the first reservoir. Experiments were carried out in the second reservoir respecting the Froude similarity, obtaining for the discharge a value Q = 0.125 l/s (Re = 10417). The aim was first of all to see if the meandering jet type developed in the scaled reservoir for the same Froude numbers of the 6 m x 4 m reservoir. In order to study the oscillation frequency of transversal velocity in the meandering jet, flows fields developing in these two experimental reservoirs have been simulated numerically with the model WOLF2D, developed at the University of Liege.

2. Numerical model

Numerical simulations were performed by the two-dimensional depth-averaged model WOLF2D. It has already been demonstrated that this model is able to reproduce successfully the different types of flow patterns developing in the EPFL experimental facility under different geometrical configurations (Dewals et al., 2008). The turbulence closure scheme adopted for the simulations is the depth-integrated k-ε model.

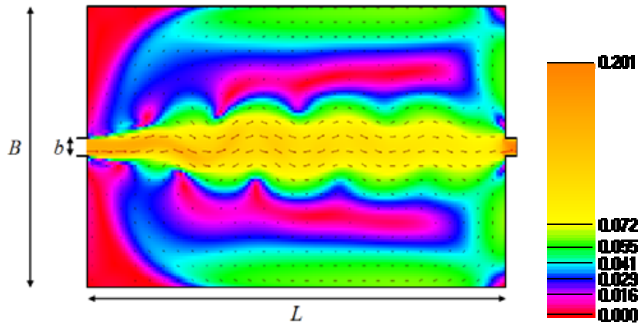

Figure 1 – Velocity map of the meandering jet (the colors indicate the absolute value of velocity [m/s]) reservoir 1.17x0.78m

3. Sensitivity analysis

The influence of the mesh size on the oscillation frequency calculated by the numerical model was checked, in order to assess the grid independency of the results. Two grids were tested for the scaled reservoir, and the corresponding Global Convergence Index GCI was calculated both for the coarse grid and for the fine grid, according to the procedure of Roache (1994): this allowed the identification of a confidence interval for the results. Sensitivity analyses were carried out also on other parameters that could affect the results of the simulations, namely the Courant number (tested values 0.5 – 0.25 – 0.125), the numerical method chosen for temporal discretization (Runge-Kutta method of first order with 3 steps, or Runge Kutta method of second order with 2 steps), the sampling frequency of the signal.

4. Results

The oscillation period T of the jet is represented by the period of oscillation of the transversal velocity V , and it was individuated by applying a discrete Fourier Transform to the velocity signal. The results of the analysis on the oscillation period for the 2 reservoir are shown in Table 1. From these results, it is shown that the ratio $T_{6x4m}/T_{1.17x0.78m}$ is about 0.45-0.5.

	Reservoir 6x4 m			**Reservoir 1.17x0.78 m**		
h [m]	0.075	0.1	0.15	0.015	0.02	0.03
V_{in} [m/s]	0.3733	0.2800	0.1867	0.1736	0.1302	0.0868
Fr_{in}	0.44	0.28	0.15	0.45	0.29	0.16
St	0.09	0.11	0.18	0.07	0.11	0.17
T [s]	7.44	7.86	7.31	3.85	3.35	3.35

Table 1 – Oscillation period, Froude number and Strouhal number for the three non-dimensional depths (h/b = 0.3 – 0.4 – 0.6) tested for the reservoirs at 2 different scales.

On the contrary the Strouhal number *St* keeps quite constant for the 2 reservoir, as required by the Froude similarity law; this parameter was calculated assuming the width b of the inlet channel as characteristic length: $St = b/V_{in}/T$, where V_{in} is the velocity in the inlet channel. The logarithmic relationship between the inlet Froude number and the Strouhal number is showed in Figure 2.

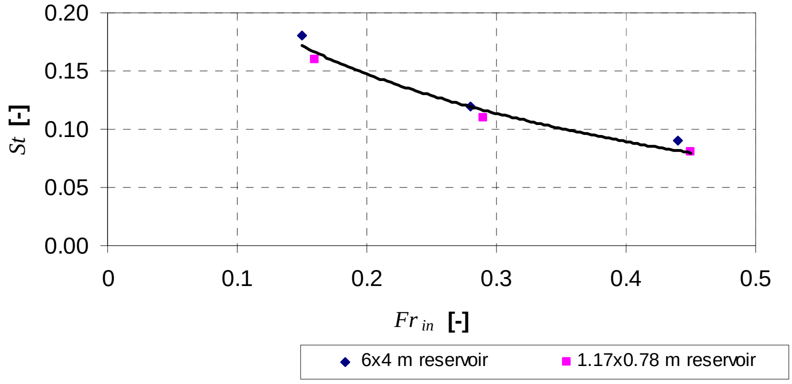

Figure 2– Strouhal-Froude relationship for the meandering jet

5. Conclusions and perspectives

This study provides a first insight into some characteristics of the meandering flow pattern type in shallow rectangular reservoirs. The oscillation frequency of velocity has been studied for one geometric reservoir configuration for different Froude numbers and at two different scales. Numerical simulations confirmed that the meandering flow arises for non-dimensional depths $h/b < 0.8$ ($Fr > 0.1$). It was shown that a variation of the Froude number in the quite wide range 0.15-0.44 doesn't influence the value of the oscillation period, but it exist a logarithmic relationship between the Strouhal and the Froude number. The following steps of this work will be to investigate the possible formation of the meandering jet flow type for other reservoir configurations and for different hydraulic conditions, assessing the influence of these parameters on the main oscillation frequency of the jet, and identifying other periodical frequencies present in the velocity signals. Furthermore, experimental data will be collected in the facility of Politecnico of Milano, in order to have confirmations of the numerical results obtained by WOLF2D.

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