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A study of the average flow in open channel with baffle blocks distributed uniformly

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Abstract

A study of average flow in open channel with baffle blocks distributed uniformly has been considered by using channel with varied slopes. In this article, experimental and modelling studies were introduced when the correlation between the water depth and baffle block size is significant. The objective of the work is to give the rudimentary relations between discharge and water level in the channels. When the water depth is large, the effect of bottom channel friction on the flow is relatively small. This paper also gives applications of the software 'Telemac-2D' to simulate the flow under different conditions.

Keywords : Telemac-2D, Drag coefficient, Emergent blocks

1 Introduction

Flow in open channels has been studied and applied to design fishway by Bathurst (Bathurst, 2002) and Cassan (Cassan L, 2014). In these studies, block size is comparable to the flow depth, and the baffle blocks can be either submerged or non-submerged. Baki (Baki A, 2014) has developed an overall analytical model based on the balance momentum. [1] in discussion of the flow in open channel with large roughness elements summarized that drag force has a substantial effect on the flow. Apart from experimental studies, mathematical models were used to make reliable results to design fishways by Chorda (Chorda J, 2010) and Tran (Tran DT, 2016). Tran (Tran DT, 2016) has used Telemac-2D to simulate the flow in the natural fishways with baffle blocks distributed uniformly. He also concluded that the mathematical model agrees sufficiently well with the experimental studies of [3] in case of Froude number is less than 0.7

In Vietnam, flow around solid bodies frequently occurs in practice, for example flow around the piers of the bridges or sea ports, the natural tree lines along many river embankments or mangrove forest. Flow in these areas has considerably high water depth in comparison with the dimensions of the piers. In this paper, we only focus on the flow with emergent baffle blocks, the water depth varies from 1.5 to 3.5 times the cylinder width, and Froude number is less than 0.3.

In experiments of this study, the circular cylinders are placed uniformly, the channel bed slope varies from 1%; 1.3%, 1.5%, 2% with different discharges. In addition, a software “Telemac-2D” was used to simulate the flow under different scenarios.

2 Physical model

long and 0.3 m wide with the slope varied from 0 to 0.02. The cylinders made of PVC have the diameter of 0.042 m and the height of 15 cm. They are distributed uniformly in channel with concentration $C = D^2/(a_x a_y)$, in which D is cylinder’s diameter, a_x and a_y are the block centre-to-centre distance in the longitudinal and transverse direction, respectively (Figure 1).

Figure 1: Experimental channel with cylinders

Two types of channel bottom were experimented: “smooth” bed is made of PVC, “rough” bed is made with 1,5 - 2,5 cm gravels distributed all over the bottom surface. Water level in the channel was measured in the absence of a large baffle blocks to estimate the Manning’s roughness coefficient of the channel bottom.

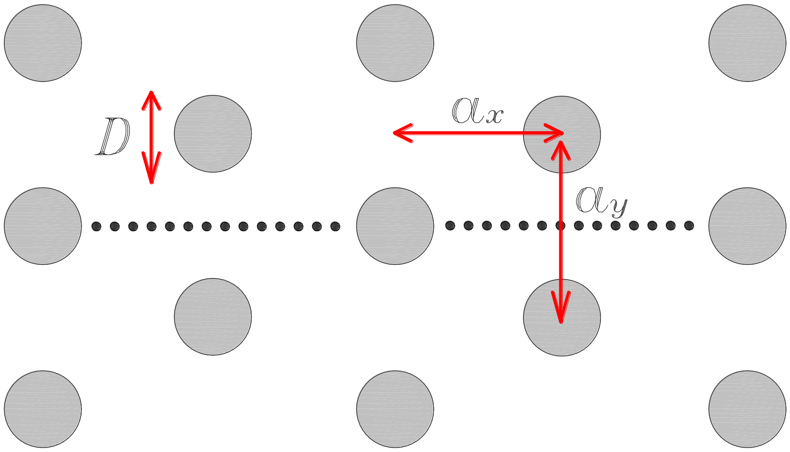

Figure 2: Points of water level measurements

An Delft Mesure - DAQ is used to measure the water level at different points along the flow (Figure 2). For each point, the water level is an average of 400 measured values. An average value of water depth H is obtained from the average water levels of 28 points.

Exp.	C	Slope (%)	Q (*l/s*)	H (cm)	F	Bed	K (Strickler)
E1	17.6	1	2.5-7	9-14.5	0.14-0.27	Smooth	100
E2	17.6	1.3	1.2-7	6-13.5	0.22-0.30	Smooth	100
E3	17.6	2	2.2-8.5	7-14.5	0.17-0.24	Smooth	100
E4	17.6	1	1.8-5.6	7.5-13	0.15-0.23	Rough	30
E5	17.6	1.5	1.8-5.6	7.5-12.5	0.16-0.25	Rough	30
E6	17.6	2	1.2-5.6	6.5-12	0.13-0.27	Rough	30

Table 1: Test channel configurations

3 Mathematical models

Telemac (Galland JC, 1991; JM, 2000) is a property of Electricité de France (EDF), used to simulate water surface profile in two-dimensions flow of horizontal space. At each point of the mesh, the program calculates the water depth and two velocity components. Turbulence modelling is obtained through k-epsilon closure model. This turbulent model was discussed in (Tran DT, 2016) for complicated flow on nature such as fishway with unsubmerged obstacles distributed uniformly.

In this study, all emergent cylinders have the diameter of 42 mm. The concentration of baffle blocks was calculated in two scenarios: C = 17.62% and C = 24.01%. The 2D triangular unstructured grid has a grid of size elements varies from about 2.6 mm to 15.6 mm, with the average value of 10 mm. The number of nodes in the model covers the range 15451 – 15850 and the number of elements was assumed to cover the range 27588 – 27832 depending on plots concentration value C (Figure 3). The bottom was modelled as a friction zone parameterized by a Strickler coefficient, where K = 30 and K = 100 equivalent to bed roughness factor in physical model.

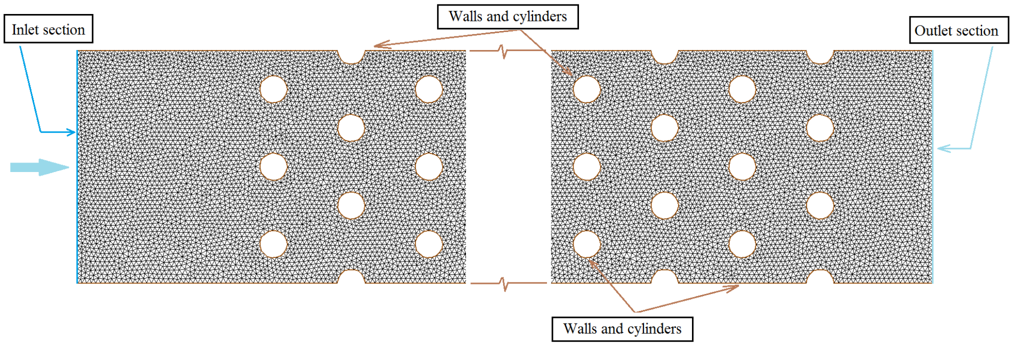

Figure 3: Detail of mesh for the channel calculation by Telemac 2D

4 Initial conditions and boundary conditions

The boundary conditions were a prescribed constant discharge at the model inlet and a depth-discharge relation at the outlet, with values corresponding to the experimental settings. At each time step, the outflow was calculated hereafter from the flow depth values at the outlet nodes using a rating curve relation in experimental study. A free slip condition is applied for boundary conditions for side walls, lateral abutments, cylinders.

5 Results

Water levels were measured on 28 nodes at different cross-sections along the channel. The experiments on the ‘smooth’ bottom were conducted with channel bottom slope of S = 1%, 1.3% and 2%, flow rate of Q = 2.2 *l/s,* 3.4 *l/s;* 4.4 *l/s,* 5.6 *l/s* and *7 l/s,* corresponding to the average water level in the channel varying from 6.9 cm to 14.5 cm; In the case of “rough” channel bottom, the experiment was conducted with bottom slope of S = 1%, 1.5% and 2%, flow rate of Q = 1.2 *l/s,* 2.5 *l/s,* 3.4 *l/s;* 4.4 *l/s,* 5.6 *l/s,* corresponding to the average water level in the channel ranged from 6.7 cm to 12.8 cm.

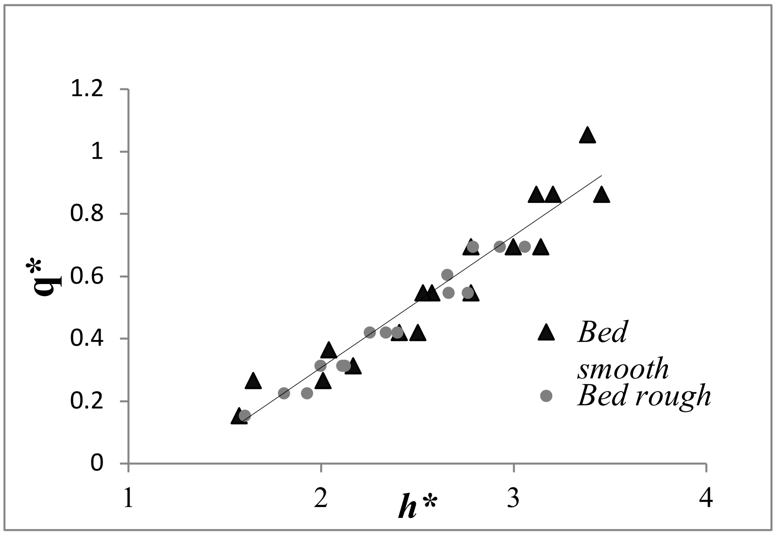

Figure 4: The Stage – discharge relationship for all experiments

Figure 4 illustrates the relationship between flow rate and the water level, which represents two dimensionless quantities: $h^* = h/D$ and $q^* = Q/(b^*g^{0.5*}D^{1.5})$, with b is the channel width, g is the gravitational acceleration, $g = 9.81$ m/s^2.

According to the Figure 4 the discharge - water level correlation coincides with two different channel bottoms. There with $1.5 \le h^* \le 3.5$, the influence of the channel bottom on the flow is insignificant. From figure 4, a simple linear relationship can be given to represent the discharge – water level relationship:

$$q^* = 0.424\frac{h}{D} - 0.5505 \qquad (R^2 = 0.929) \qquad (1)$$

Equation (1) shows a scenario of block density in the channel of $C = 17.62$, which requires further experiments with other densities to calibrate this equation. This relationship is also used to make the boundary condition in the Telemac-2D model.

A big attention was paid to the drag coefficient, when the coefficient h* was large, the influence of the frictional force was insignificant and has been neglected in this study. For uniform flow regime, the drag force is balanced with gravity force in the direction of the flow. According to [3] there are:

$$\frac{1}{2}C_d\frac{Ch}{D}V_g^2 = ghS(1-\frac{\pi}{4}C) \qquad (2)$$

Therefore:

$$C_d = \frac{1}{Fr^2}\frac{2S(1-\frac{\pi}{4}C)}{Ch^*} \qquad (3)$$

$$V_g = \sqrt{\frac{2gSD(1-\frac{\pi}{4}C)}{C_d C}} \qquad (4)$$

in which V_g is the average velocity between the blocks; Fr - Froude number, $Fr = V_g / \sqrt{gh}$.

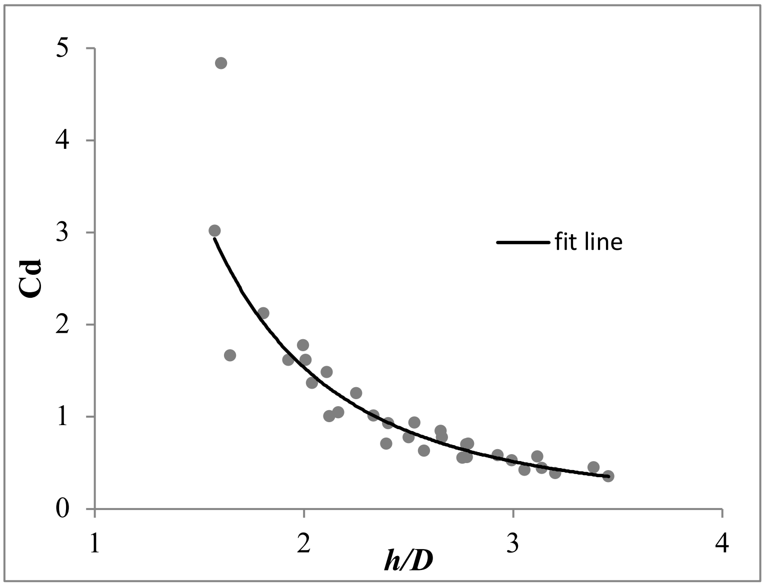

Figure 5: Drag coefficient as a function of h* = h/D

Figure 5 shows the relationship between C_d and *h/D* for both smooth and rough bottoms. The fit line was built according to power equation to describe this correlation:

$$C_d = 9.9162\left(\frac{h}{D}\right)^{-2.692} \qquad (R^2 = 0.91) \qquad (5)$$

Figure 6 shows the relationship between the actual discharge and the discharge calculated from formula (5). Equation (5) agrees sufficiently well with the results of the experiment, the error between calculated flow rate and the measured flow rate is less than 10%.

Telemac-2D was used to simulate the flow with C = 17.62% and C = 24.01%, and the bottom slope of S = 1%, 2%, 3%, 4%. According to [7], the Telemac-2D model is consistent with stage-discharge relationship of [3], where Fr <0.7 and h/D <1.2.

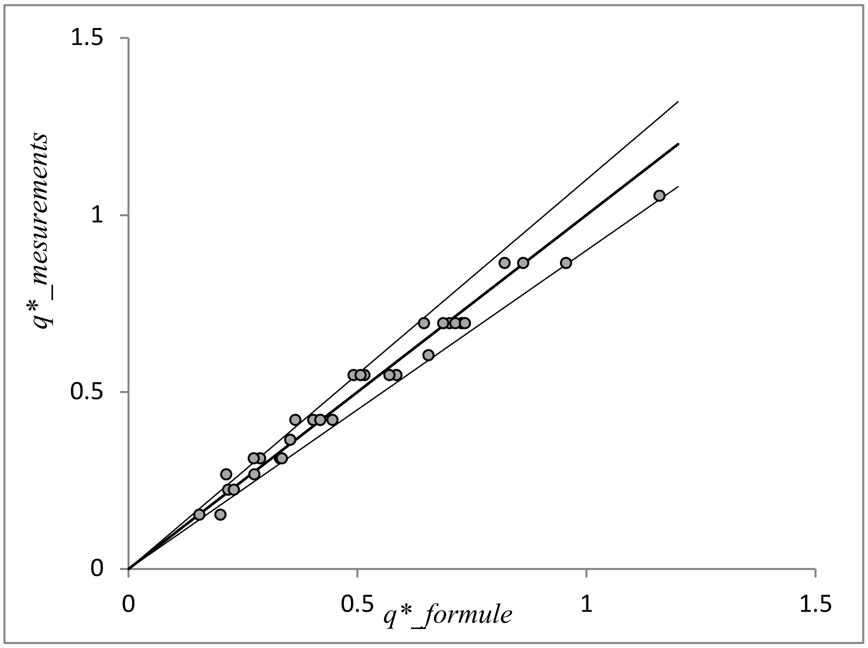

Figure 6: Comparison of dimensionless discharge between measured and calculated by formule (4)

Figure 7 shows the error between the measured discharge and calculated discharge using Telemac-2D. When $h/D \leq 1.2$, Telemac-2D agrees sufficiently well with stage-discharge of [3]. As h^* increases the error increases rapidly, both field data and Telemac-2D's results show that the error tends to decrease rapidly as h^* approaches 3.

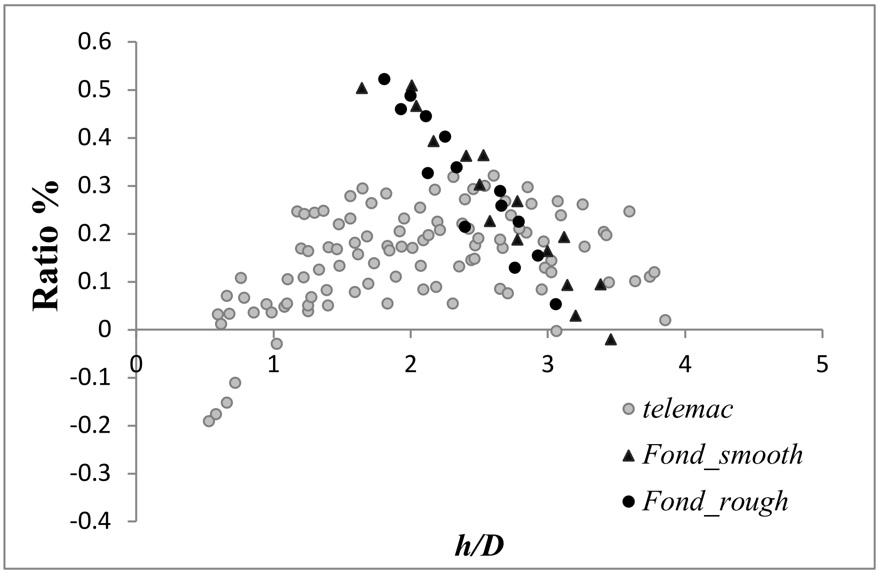

Figure 7: The error of the measured net load and Telemac-2D with flow was determined according to the stage-discharge relationship of [3].

Experimental results were made for a case of density C = 17.62%, bottom slope of $S \leq 2\%$; the coefficient h^* is in the range of 1.5 to 3.5. Experimental data was limited, so more experiments are needed to calibrate the given formulas as well as to check the trend in the Figure 7.

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