Experimental Study of Subcritical Dividing Flow in an Equal-Width, Four-Branch Junction

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Abstract: An experimental study of the subcritical dividing flow in an equal-width, four-branch junction with two inflows and two outflows is presented. A brief description of the flow characteristics is given. From the analysis of test data, a linear relationship among five nondimensional parameters, including inflow ratio, outflow ratio, Froude number of inflow in one direction, outflow depth ratio, and outflow aspect ratio, is proposed and proven to successfully predict the flow distribution in the junction. It can be used to solve the dividing flow problem in a street junction, and it can be included as a part of a numerical model of a street network involving subcritical flows.
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Introduction

Predicting street flow is important in severe and even in moderate storm events because flow to the urban drainage system is conveyed in streets and may contribute to hazards for street users, both pedestrian and drivers (Nanía-Escobar et al. 2006). The flow in a street has some particular features such as aspect ratios (i.e., width over depth), which can be of the order of several tens and even a few hundreds. The flow can be considered to be one-dimensional while moving in the street, but this approximation is not valid in the crossing where the flow could be two- or three-dimensional. The use of a two- or three-dimensional model to simulate an extensive urban area, formed primarily by a street network, could be too computationally expensive and even unnecessary. The primary aim of the present work is to develop a relatively simple approach on the basis of the one-dimensional Saint-Venant equations that avoids the difficulties associated with two- and three-dimensional modeling but that empirically includes the multidimensional effects investigated in the laboratory. Nanía (1999), Nanía et al. (2004) and Mignot (2005) studied the problem involving supercritical flows in open-channel four-branch junctions. In this paper, the problem involving subcritical dividing flows with equal width, rectangular cross section, and two inflows and two outflows is addressed, and the flow distribution is determined by using a relationship among the involved variables. Experiments were conducted to find these relationships, and the results are presented as a first approximation to the study of the subcritical flows in street crossings. The street crossing is a particular type of open-channel four-branch junction. The determined relationship may be included in a numerical model to solve the unsteady flow in a street network involving subcritical flows by using a one-dimensional approach.

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Previous Work

No work has been found concerning the subcritical flow in open-channel four-branch junctions. However, a number of studies have been reported with open-channel (three-branches) junctions and bifurcations with subcritical flow. Taylor (1944) pioneered the study of three-branch open-channel junctions and bifurcations involving subcritical flows. The only two works reporting the study of flow in open-channel four-branch junctions but with supercritical flows are those by Nanía et al. (2004) and Mignot (2005).

Study Approach

Types of Junctions

Because channels converge in an open-channel four-branch junction and two possible types of flow are possible in each channel (i.e., subcritical or supercritical); 16 different types of junction flows may be identified on the basis of the flow regime in each channel. The case in which the four channels converging in the junction have steep slopes has been studied (Nanía 1999; Nanía et al. 2004; Mignot 2005). In this paper, the study of the full subcritical junction (i.e., four channels with subcritical flow converging in the junction) is addressed. From the point of view of the flow distribution, the following cases may be distinguished:

1. Three inflows and one outflow, trivial;
2. Two inflows and two outflows;

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a. Each inflow corresponding to one outflow in the same direction;
b. Inflows and outflows having opposite directions; and
3. One inflow and three outflows.

This work is restricted to Case 2a.

Boundary Conditions

The boundary conditions that fix the hydraulic behavior of the junction with subcritical flow are

- Upstream (i.e., input channels): Inflows Q_{ix} and Q_{iy}; and
- Downstream (i.e., output channels): Either outflow Froude numbers F_{ox} and F_{oy} or outflow depths y_{ox} and y_{oy}.

Dimensional Analysis

The variables involved in the subcritical dividing flow problem that occurs in a right-angled, equal-width, open-channel, four-branches junction are the inflows in both directions or the inflow in one direction and the sum of inflows, Q_{ix} and Q_T, respectively; the outflow in one direction, Q_{ox}; the average depths in the cross sections just upstream and downstream of the junction; y_{ix}, y_{iy}, y_{ox}, and y_{oy}, respectively; the channel width, b; the flow density, ρ; the dynamic viscosity of flow, μ; gravitational acceleration, g; and the effective surface roughness height, k_s. The dependent variables are Q_{ox}, for being the unknown of the problem, and y_{ix} and y_{iy}, for being the flow subcritical everywhere. By applying the Pi theorem, the result is the following relationship among nondimensional parameters:

$$f_1\left(\frac{Q_{ix}}{Q_T},\frac{Q_{ox}}{Q_T},\frac{b}{y_{ix}},\frac{b}{y_{ox}},\frac{b}{y_{iy}},\frac{b}{y_{oy}},\mathsf{F}_{ix},\mathsf{R}_{ix},\frac{k_s}{b}\right)=0 \quad (1)$$

where Q_{ix}/Q_T = inflow ratio; Q_{ox}/Q_T = outflow ratio; b/y_{ix}, b/y_{ox}, b/y_{iy}, and b/y_{oy} = aspect ratio of the incoming and outcoming flows; F_{ix} and R_{ix} = Froude and Reynolds numbers, respectively, of the inflow in the x-direction; and k_s/b = dimensionless surface roughness. Again, Q_{ox}/Q_T, b/y_{ix}, and b/y_{iy} can be distinguished as the dependent nondimensional parameters. By assuming a high degree of turbulence (i.e., large Reynolds numbers), the influence of R_{ix} can be considered negligible in the flow distribution and will not be accounted for in this case, for the sake of simplicity. In this study, the dividing flow process can be considered a local phenomenon, so friction losses are neglected. Because of this, the influence of the surface roughness height, k_s, can be considered negligible and is not taken into account. The dependent nondimensional parameters b/y_{ix} and b/y_{iy} are highly correlated with the independent nondimensional parameters b/y_{oy} and b/y_{ox}, respectively, which demonstrates their dependence; thus, they can be removed from the analysis. The Froude number F_{ix} is retained as an independent dimensionless variable because it is defined as $Q_{ix}/(by_{ix}^{1.5}\sqrt{g})$ where y_{ix}, which is a dependent variable, can be predicted very approximately by the mean of y_{ox} and y_{oy}, both independent variables. Finally, rearranging parameters, the relevant relationship to be studied is found to be one with five nondimensional parameters:

$$\frac{Q_{ox}}{Q_T}=f_2\left(\frac{Q_{ix}}{Q_T},\frac{b}{y_{ox}},\frac{y_{ox}}{y_{oy}},\mathsf{F}_{ix}\right) \quad (2)$$

Experimental Study

Description of Experimental Setup

A model of a 90° four-branch open-channel junction was constructed (Fig. 1). The channels have a rectangular cross section of 1.5 m width and 0.35 m depth. The junction was formed by a 1.5 m square. Input channels and output channels were 2 and 5 m long, respectively. The junction and the channels were fixed in a horizontal position. Fig. 1 depicts a sketch of the experimental set up and its dimensions. The downstream boundary conditions were changed by using weirs of several heights at the end of the channels.

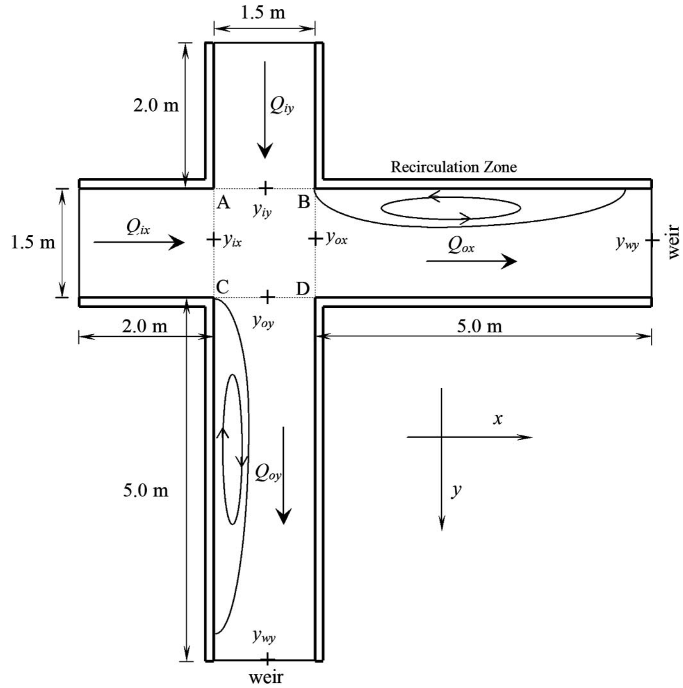

Fig. 1. Experimental setup with dimensions, showing flow parameters and location of recirculation zones

Tests were conducted with different inflow ratios and several combinations of downstream boundary conditions (i.e., weir heights). Thirty combinations of inflow ratios were carried out involving inflow ratios from 0.1 to 0.9 and discharges in each input channel from 6 to 75 L/s. The discharges in the input channels were controlled independently by valves. Six combinations of weir heights were used for every inflow ratio. More details about the test planning can be found in Comas-Pelegrí (2005). The ranges of the rest of the studied parameters were as follows:

- Water depths in the input channels just upstream of the junction were 4.0–16.2 cm;
- Outflow depths immediately after the junction (average in the cross section) were 4.1–15.8 cm;
- Outflow aspect ratios (i.e., width/depth) immediately after the junction (average) were 9.5–37;
- Input Froude numbers just upstream of the junction were 0.034–0.79; and
- Nondimensional total discharge $(Q_T/b/y_{ox}^{1.5}/g^{0.5})$ was 0.24–0.92.

The parameters measured were two inflows, Q_{ix} and Q_{iy}; one outflow, Q_{ox}; water depths in the input streets just upstream of the junction, y_{ix} and y_{iy}; and the depths in three sections of the output channels (1) immediately after the junction, y_{ox} and y_{oy}; (2) 2.5 m downstream of the junction; and (3) just upstream of the weirs, y_{wx} and y_{wy} (see Fig. 1). Both the input discharges and the output discharge in the x-direction were measured with 90°-V-notch weirs, and the depths were measured with point gauges. The water levels over the V-notch weirs were also measured with point gauges. All point gauges measured with a resolution of 0.1 mm. A maximum uncertainty of ± 1 mm was

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expected in the measure of the water level for the output discharge in the x-direction and in the water depths in the channels. The measure of the input discharges was made with an uncertainty only corresponding to the precision of the device (i.e., less than 0.25%). The uncertainty in the measure of water depth in the channels was inside ±2.5%. On the other hand, the error in the measure of the output discharge, ε_q, could be related to the water level error, ε_y, as $\varepsilon_q = [1 - (1 + \varepsilon_y)^{2.5}]$ and was found to be less than ±2.3%. More details about the uncertainty analysis of the measures can be found in Nanía (1999).

Results and Discussion

Flow Descriptions

Depths and Wave Formation

Subcritical flow prevailed in all experiments. Depths were observed to be quite uniform in the junction area for every experiment, especially the depths immediately before the junction, in agreement with Taylor (1944) and were more uniform with a decreasing Froude number. A rise in the depth was detected in the dividing corner of the junction (Corner D in Fig. 1), increasing with the Froude number. Wave formation was observed, especially in the input channel in which the inflow ratio was equal to or greater than 0.8, and the depths in the output device were small. This fact made the measurement of depths difficult in these few cases. Such waves also extended to the junction and even to both output channels. In a few cases, they were up to 2 cm in height with wavelengths of nearly 20 cm, but these data were not considered in the analysis.

Recirculation Zones

Two recirculation zones were observed to exist in both output channels that began just next to the corner with the input channel (Corners B and C in Fig. 1) and extended almost to the end of the output channels. The depth of the recirculation zone was quite similar to that of the flow, and its width was between one fourth and two thirds the channel width. The width increased with the increasing inflow ratio in the perpendicular direction. Although the outflows were not one-dimensional because of the presence of the recirculation zones, the existence of the weirs at the end of the output channels influenced the outflow to be more one-dimensional near them. According to the analyses by Weber et al. (2001), who reported recirculation zone lengths up to six times the channel width, the recirculation zones were expected to extend further if the output channels were longer. More details about the flow description can be found in Comas-Pelegrí (2005).

Relationships Among Involved Variables

General Trends

In the following discussion, the weir heights are considered to classify the experiments according to their boundary conditions, but the reader should understand that the true boundary conditions are constituted by the depths immediately after the junction y_{ox} and y_{oy}. The first analyses were addressed to find the general behavior trends of the flow distribution. In considering the 79 cases for which the boundary conditions were constituted by equal weir heights in both directions, the trend observed is that the greater the inflow ratio, Q_{ix}/Q_T, the greater the outflow ratio, Q_{ox}/Q_T, but whereas the inflow ratio changes over a range of 0.8 (i.e., from 0.1 to 0.9), the outflow ratio varies only over a range of 0.21 (i.e., from 0.51 to 0.72). Thus, the junction works as an equalizer of the flow distribution. Further, the higher the weirs, the narrower the range of outflow ratio observed (i.e., 0.21 for 2–2 cm and less than 0.1 for 8–8 cm).

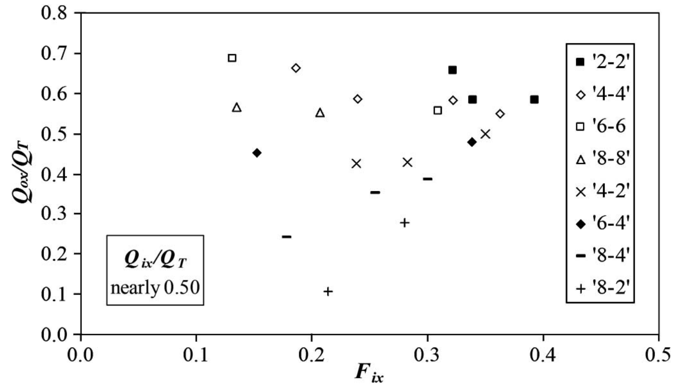

Fig. 2. Influence of the inflow Froude number in the flow distribution; in the legend, '8-4' indicates weir height of 8 cm in x-direction and weir height of 4 cm in y-direction

The results for Q_{ox}/Q_T for the 11 tests in which $Q_{ix}/Q_T \approx 0.5$ and the boundary conditions (i.e., weir heights) were the same in both directions are plotted against the Froude number of the inflow in the x-direction, F_{ix}, as shown in Fig. 2. For a given F_{ix}, the larger Q_{ox}/Q_T corresponds to the cases for which the weir was lower, but its influence was very weak.

To observe the influence of the boundary conditions (i.e., weir heights), 10 cases in which the $Q_{ix}/Q_T \approx 0.5$ but the boundary conditions were different in each direction are presented in Fig. 2. The lower the value of F_{ix}, the larger the influence of an unequal boundary condition combination over Q_{ox}/Q_T.

Relationship Among Water Depths

For a given case, a strong relationship was found among the water depths near the junction. This was expected because the subcritical flow depends on the downstream boundary condition, so all water depths in the junction region tend to be quite similar. The strong correlation between b/y_{ix} and b/y_{oy} ($r^2 = 0.93$), on the one hand, and b/y_{iy} and b/y_{ox} ($r^2 = 0.97$), on the other hand, was used to reduce the number of nondimensional parameters included in the regression analysis from seven to five.

Regression Analysis

A momentum balance in the junction was implemented to find a relationship among Q_{ox}/Q_T and the remaining variables, but the result was not satisfactory, probably because the hypotheses considered (i.e., one-dimensional inflows and outflows) were far from reality, as expected when one observes the flow features in the experiments. Evidently, some flow characteristics that were not quantitatively described in the laboratory (e.g., effective widths of flow, contraction coefficients, and recirculation zones) and are needed to obtain a satisfactory description of the flow distribution must be needed with that approach. The energy approach also failed to give a satisfactory answer, probably for the same reason.

Table 1. Nondimensional Parameters Used in Regression Analysis and Intervals Assumed

Nondimensional parameter	Full range	Intervals 1	Intervals 2	Intervals 3
$a_3 = b/y_{ox}$	9.49–29.41	9.49–13	13–17	17–29.41
$a_4 = y_{ox}/y_{oy}$	0.994–1.493	0.994–1.1	1.1–1.2	1.2–1.493

Table 2. Coefficients Used in Eq. (3) for Cases Defined by Given Combination of b/y_{ox} and y_{ox}/y_{oy}

Interval	Number of observations	Coefficients in Eq. (3)					r^2
		A	B	C	D	E	
a3-1; a4-1	29	3.54×10^{00}	-2.96×10^{00}	4.94×10^{-01}	-3.54×10^{-04}	-3.31×10^{-01}	0.81
a3-1; a4-2	16	3.55×10^{00}	-2.99×10^{00}	2.18×10^{-01}	-8.32×10^{-03}	7.28×10^{-01}	0.92
a3-1; a4-3	7	1.32×10^{00}	-1.91×10^{-02}	4.87×10^{-01}	-8.42×10^{-02}	-8.01×10^{-01}	0.98
a3-2; a4-1	14	1.77×10^{00}	-1.04×10^{00}	1.15×10^{00}	-1.25×10^{-02}	-1.50×10^{00}	0.65
a3-2; a4-2	26	3.25×10^{00}	-3.32×10^{00}	2.68×10^{-01}	4.69×10^{-02}	5.71×10^{-01}	0.73
a3-2; a4-3	13	-1.46×10^{00}	3.88×10^{-01}	-5.05×10^{-01}	7.45×10^{-02}	1.62×10^{00}	0.83
a3-3; a4-1	11	6.01×10^{-01}	-5.96×10^{-01}	6.72×10^{-01}	1.80×10^{-02}	-1.76×10^{-01}	0.8
a3-3; a4-2	27	3.69×10^{00}	-3.29×10^{00}	5.18×10^{-01}	1.90×10^{-02}	-2.24×10^{-02}	0.7
a3-3; a4-3	16	1.33×10^{-01}	-3.86×10^{-01}	-1.61×10^{-01}	2.67×10^{-02}	8.88×10^{-01}	0.85
Total	159					Global r^2	0.82

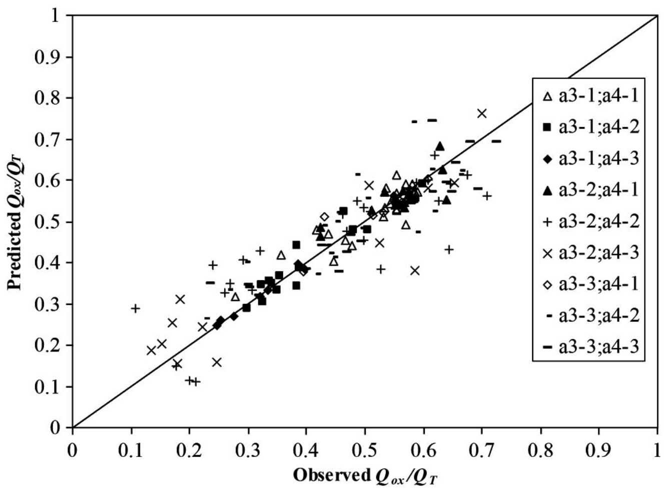

Fig. 3. Observed versus predicted outflow ratios from Eq. (3) with coefficients from Table 2 for the parameter intervals in Table 1

Instead of such traditional approaches, a regression approach was undertaken. First, the range of nondimensional parameters to be used was established, as presented in Table 1, and then the results were fitted over a range of selected intervals to a model of the form

$$\frac{Q_{ox}}{Q_T} = A + B^*\left(\frac{y_{ox}}{y_{oy}}\right) + C^*\left(\frac{Q_{ix}}{Q_T}\right) + D^*\left(\frac{b}{y_{ox}}\right) + E^*(\mathsf{F}_{ix}) \qquad (3)$$

by using nine intervals defined by the downstream boundary conditions, namely the water depths and the aspect ratio of the outflow through the parameters b/y_{ox} and y_{ox}/y_{oy}. In Eq. (3), A, B, C, D, and E are the regression coefficients, which are presented in Table 2 for every interval together with their coefficient of determination, r^2. A global coefficient of determination, r^2, of 0.82 was obtained, although the individual coefficients of determination within every interval ranged from 0.65 to 0.98. A nonlinear regression analysis was also considered, but this yielded a slightly lower value of r^2.

The coefficient D had a small value, but it was verified that it was not statistically zero. Regarding the confidence intervals of 95% of the coefficients, the amplitude of them was very variable from one range to another and from one coefficient to another inside of the same range, without observing any particular trend. For that reason, it was considered acceptable to define the coefficients with no more than three significant figures.

The observed versus predicted outflow ratios with the coefficients of Table 2 are presented in Fig. 3. The experimental data are presented in Table 3.

Conclusions

An experimental study of the subcritical dividing flow with two inflows and two outflows was presented. A brief description of the flow was provided that included the formation of waves and the existence of two recirculation zones. On the basis of a dimensional analysis and laboratory experiments, five nondimensional parameters were found to be necessary to describe the flow distribution in a four-branch junction with subcritical flow: inflow ratio, outflow ratio, Froude number of the inflow in one direction, outflow depth ratio, and aspect ratio of the outflow in one direction. Experiments were performed with a 150-cm-wide rectangular cross section street crossing. A linear relationship of the nondimensional parameters together with a set of coefficients for a given downstream boundary condition combination was developed to predict the flow distribution. Although these results should be treated as a first approximation, the approach presented in this work to find the flow distribution under subcritical conditions could be used to study the flow in a street network, provided that both the characteristics of the crossings and the flow are the same of those of the experiments presented: a right-angled, sharp-edged, equal-width, open-channel, four-branch junction with Froude numbers between 0.034 and 0.79, aspect ratios of flow (i.e., width over depth) between 9.5 and 37, and a nondimensional total discharge (i.e., $Q_T/b/y_{ox}^{1.5}/g^{0.5}$) between 0.24 and 0.92. Further efforts should be addressed to include the influence of other characteristics, for example non-equal-width channels/streets, transverse slopes in the streets, presence of sidewalks, and non-right-angled crossings, in the flow distribution in the junction.

Acknowledgments

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Table 3. Experimental Data

x-weir (cm)	y-weir (cm)	Q_{ix} (L/s)	Q_{iy} (L/s)	Q_{ox} (L/s)	y_{ix} (cm)	y_{iy} (cm)	y_{ox} (cm)	y_{oy} (cm)
4	2	8.42	74.75	32.77	8.42	8.94	8.07	7.84
4	4	8.42	74.75	42.43	9.27	10.21	9.57	9.35
8	2	8.42	74.75	14.68	9.80	10.96	10.55	9.15
8	4	8.42	74.75	23.05	10.87	11.71	11.77	10.71
8	8	8.42	74.75	44.20	13.11	13.88	13.89	13.42
6	4	5.88	49.80	23.59	8.57	9.12	9.42	8.69
6	6	5.88	49.80	31.19	9.33	10.02	10.11	9.59
2	2	6.13	25.39	18.18	4.68	5.43	5.24	4.83
4	2	6.13	25.39	12.55	5.45	6.31	6.48	5.54
4	4	6.13	25.39	19.44	6.39	7.20	7.36	6.62
6	2	6.13	25.39	7.15	6.08	6.92	7.23	6.06
6	4	6.13	25.39	13.73	7.13	8.02	8.29	7.38
6	6	6.13	25.39	20.11	7.94	8.76	9.01	8.22
8	2	18.80	73.92	19.46	10.55	11.42	11.17	9.53
8	4	18.80	73.92	33.13	11.31	11.93	11.82	10.99
8	8	18.80	73.92	51.08	13.54	14.33	14.19	13.68
2	2	12.75	49.61	33.09	6.76	7.55	6.60	6.57
4	2	12.75	49.61	25.99	7.50	8.21	8.16	7.11
4	4	12.75	49.61	35.38	8.42	9.07	8.84	8.45
8	2	12.75	49.61	8.36	9.04	9.90	10.01	8.24
8	4	12.75	49.61	16.21	10.05	10.87	10.98	9.94
8	8	12.75	49.61	34.35	11.95	12.91	12.81	12.33
4	4	31.36	74.93	55.91	10.66	11.28	11.21	10.10
6	4	31.36	74.93	47.45	11.32	12.07	11.65	10.71
6	6	31.36	74.93	57.02	12.10	13.88	12.40	12.04
8	4	31.36	74.93	34.35	12.11	12.93	12.67	11.52
8	6	31.36	74.93	44.28	13.18	14.01	13.78	12.92
8	8	31.36	74.93	62.19	14.32	15.14	14.92	14.38
2	2	24.62	58.35	42.64	8.55	8.89	7.72	7.69
4	2	24.62	58.35	35.15	8.87	9.53	9.02	8.25
4	4	24.62	58.35	44.20	9.61	10.35	9.78	9.41
8	2	24.62	58.35	16.57	10.27	11.09	11.03	9.28
8	4	24.62	58.35	24.71	11.00	11.96	11.91	10.69
8	8	24.62	58.35	44.20	13.10	13.89	13.78	13.10
2	2	10.56	24.80	21.10	5.07	5.85	5.71	5.00
4	2	10.56	24.80	14.92	5.85	6.77	6.80	5.85
4	4	10.56	24.80	21.69	6.71	7.58	7.67	6.92
6	2	10.56	24.80	9.44	6.45	7.32	7.58	6.41
6	4	10.56	24.80	15.92	7.49	8.39	8.52	7.61
6	6	10.56	24.80	22.38	8.22	9.06	9.25	8.45
2	2	21.44	50.04	39.19	7.45	8.23	6.90	6.94
4	2	21.44	50.04	31.83	8.16	8.91	8.54	7.46
4	4	21.44	50.04	40.59	8.90	9.72	9.37	8.82
8	2	21.44	50.04	12.88	9.66	10.56	10.66	8.80
8	4	21.44	50.04	21.98	10.42	11.40	11.38	10.23
8	8	21.44	50.04	40.63	12.36	13.30	13.36	12.52
2	2	24.80	37.83	34.77	7.02	7.85	7.20	6.74
4	2	24.80	37.83	26.95	7.62	8.61	8.27	7.72
4	4	24.80	37.83	35.45	8.52	9.37	9.08	8.43
8	2	24.80	37.83	9.56	9.19	10.12	10.27	8.51
8	4	24.80	37.83	16.83	10.08	11.05	11.12	9.88
8	8	24.80	37.83	33.98	12.04	12.94	12.99	12.22
2	2	16.42	24.87	24.71	5.45	6.35	6.08	5.31
4	2	16.42	24.87	18.16	6.24	7.18	7.22	6.14
4	4	16.42	24.87	25.14	6.96	7.99	8.00	7.15
6	2	16.42	24.87	12.22	6.94	7.87	8.01	6.84

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Table 3. (*Continued.*)

x-weir (cm)	y-weir (cm)	Q_{ix} (L/s)	Q_{iy} (L/s)	Q_{ox} (L/s)	y_{ix} (cm)	y_{iy} (cm)	y_{ox} (cm)	y_{oy} (cm)
6	4	16.42	24.87	19.07	7.75	8.75	8.86	7.89
6	6	16.42	24.87	25.96	8.51	9.43	9.59	8.79
2	2	33.32	49.52	46.68	8.10	9.11	7.75	7.34
4	2	33.32	49.52	38.75	8.85	9.73	9.14	7.97
4	4	33.32	49.52	47.63	9.47	10.40	9.84	9.25
8	2	33.32	49.52	20.41	10.20	11.25	11.19	9.24
8	4	33.32	49.52	26.89	11.14	12.13	12.10	10.73
8	8	33.32	49.52	45.87	13.10	14.04	14.01	13.24
4	4	50.27	74.69	68.92	11.50	12.32	11.30	10.57
6	4	50.27	74.69	59.55	12.08	13.01	12.37	11.41
6	6	50.27	74.69	69.32	12.91	13.85	13.26	12.54
8	4	50.27	74.69	44.20	13.14	14.04	13.65	12.20
8	6	50.27	74.69	54.67	14.18	14.96	14.67	13.57
8	8	50.27	74.69	68.98	15.02	16.03	15.80	15.00
2	2	23.98	25.21	28.60	6.09	7.07	6.61	5.99
2	2	50.08	51.41	58.97	9.03	10.10	8.22	7.91
2	2	12.30	12.16	16.01	4.04	5.09	5.10	4.08
4	2	23.98	25.21	21.07	6.88	7.95	7.78	6.70
4	2	50.08	51.41	50.46	9.75	10.77	9.84	8.50
4	2	12.30	12.16	10.40	4.95	5.89	6.15	5.03
4	4	23.98	25.21	28.77	7.69	8.43	8.53	7.80
4	4	50.08	51.41	59.23	10.30	11.34	10.51	9.80
4	4	74.81	74.45	82.06	12.44	13.62	11.80	11.26
4	4	12.30	12.16	16.18	5.83	6.82	7.00	6.15
6	2	12.30	12.16	5.77	5.53	6.55	6.85	5.67
6	4	74.81	74.45	71.57	13.03	14.27	13.29	11.91
6	4	12.30	12.16	11.09	6.67	7.59	7.91	6.86
6	6	74.81	74.45	82.83	13.84	14.95	14.03	13.16
6	6	12.30	12.16	16.78	7.37	8.34	8.67	7.70
8	2	23.98	25.21	5.30	8.28	9.42	9.56	8.03
8	2	50.08	51.41	28.10	11.30	12.42	12.09	9.87
8	4	23.98	25.21	11.84	9.37	10.39	10.51	9.28
8	4	50.08	51.41	35.60	12.04	12.92	12.94	11.32
8	4	74.81	74.45	57.28	14.11	15.24	14.81	12.81
8	6	74.81	74.45	69.60	14.90	16.13	15.67	14.32
8	8	23.98	25.21	27.80	11.26	12.24	12.35	11.47
8	8	50.08	51.41	56.21	13.85	14.93	14.82	13.84
2	2	49.10	33.24	50.04	7.82	9.13	8.09	7.44
4	2	49.10	33.24	41.71	8.45	9.81	9.36	7.80
4	4	49.10	33.24	49.94	9.28	10.50	9.99	8.90
8	2	49.10	33.24	20.30	10.35	11.57	11.60	9.29
8	4	49.10	33.24	27.70	11.02	12.23	12.20	10.62
8	8	49.10	33.24	47.45	13.00	14.05	14.15	13.13
2	2	37.43	24.87	36.61	6.81	7.88	7.38	6.21
4	2	37.43	24.87	28.40	7.58	8.72	8.53	7.06
4	4	37.43	24.87	36.45	8.24	9.35	9.90	8.17
8	2	37.43	24.87	10.60	9.11	10.28	10.38	8.57
8	4	37.43	24.87	20.03	9.80	10.86	10.95	9.63
8	8	37.43	24.87	36.80	11.71	12.74	12.83	11.88
2	2	25.24	16.74	26.86	5.37	6.46	6.24	5.15
4	2	25.24	16.74	19.65	6.18	7.29	7.38	6.14
4	4	25.24	16.74	26.79	6.99	8.07	8.15	7.14
6	2	25.24	16.74	13.34	6.89	8.02	8.17	6.73
6	4	25.24	16.74	20.41	7.75	8.82	9.02	7.91
6	6	25.24	16.74	26.99	8.51	9.48	9.66	8.37
4	4	74.99	49.61	73.21	11.19	12.60	11.40	10.29

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Table 3. (*Continued.*)

x-weir (cm)	y-weir (cm)	Q_{ix} (L/s)	Q_{iy} (L/s)	Q_{ox} (L/s)	y_{ix} (cm)	y_{iy} (cm)	y_{ox} (cm)	y_{oy} (cm)
6	4	74.99	49.61	62.99	11.97	13.27	12.68	11.19
6	6	74.99	49.61	72.15	12.79	13.94	13.41	12.16
8	4	74.99	49.61	48.32	13.01	14.28	13.88	12.01
8	6	74.99	49.61	57.94	13.86	15.26	14.95	13.53
8	8	74.99	49.61	69.09	14.97	16.06	15.76	14.91
2	2	58.46	28.13	52.95	7.84	9.39	8.30	7.28
4	2	58.46	28.13	43.12	8.69	10.02	9.61	8.16
4	4	58.46	28.13	49.80	9.50	10.71	10.32	9.07
8	2	58.46	28.13	21.95	10.44	11.85	11.79	9.66
8	4	58.46	28.13	28.87	10.98	12.46	12.43	8.81
8	8	58.46	28.13	48.04	13.14	14.20	14.39	13.25
2	2	49.15	21.30	45.69	6.85	8.47	7.75	6.19
4	2	49.15	21.30	35.91	7.68	9.32	9.02	7.53
4	4	49.15	21.30	42.73	8.64	9.85	9.75	6.53
8	2	49.15	21.30	15.64	9.61	9.94	11.06	9.01
8	4	49.15	21.30	24.01	10.53	11.67	11.81	10.16
8	8	49.15	21.30	40.88	12.27	13.49	13.57	12.51
4	4	74.99	31.51	66.67	9.69	11.74	10.92	9.45
8	2	74.99	31.51	34.06	11.23	12.86	12.84	10.15
8	4	74.99	31.51	40.79	12.08	13.57	13.49	11.69
8	8	74.99	31.51	62.08	13.93	15.34	15.32	14.11
2	2	24.87	10.18	23.80	4.68	5.91	5.79	4.63
4	2	24.87	10.18	16.69	5.64	6.82	6.99	5.65
4	4	24.87	10.18	23.26	6.54	7.60	7.75	6.71
6	2	24.87	10.18	10.56	6.44	7.55	7.77	6.30
6	4	24.87	10.18	16.96	7.30	8.39	8.62	7.51
6	6	24.87	10.18	23.68	8.05	9.08	9.32	8.33
2	2	49.80	13.11	38.71	5.66	7.74	7.48	5.81
4	2	49.80	13.11	31.44	7.03	8.65	8.58	6.69
4	4	49.80	13.11	38.91	7.89	9.24	9.13	7.88
8	2	49.80	13.11	11.61	8.98	10.40	10.66	8.56
8	4	49.80	13.11	18.36	9.87	11.21	11.35	9.73
8	8	49.80	13.11	35.87	11.83	12.96	13.19	12.01
2	2	24.59	6.42	22.44	4.35	5.58	5.72	4.20
4	2	24.59	6.42	15.29	5.42	6.60	6.85	5.20
4	4	24.59	6.42	21.47	6.23	7.38	7.55	6.37
6	2	24.59	6.42	9.39	6.17	7.29	7.61	5.93
6	4	24.59	6.42	15.59	7.07	8.15	8.46	7.17
6	6	24.59	6.42	21.95	7.79	8.87	9.19	8.02
4	4	74.63	19.07	61.23	9.28	10.96	10.57	8.42
8	4	74.63	19.07	36.18	11.53	12.91	13.10	10.88
8	8	74.63	19.07	55.11	13.40	14.63	14.81	13.32
6	4	50.08	5.57	29.18	8.08	9.43	9.84	8.04
6	6	50.08	5.57	35.95	8.82	10.08	10.50	9.16
4	4	75.05	8.26	58.20	8.37	9.99	10.24	7.70
8	4	75.05	8.26	33.02	10.91	12.39	12.66	10.53
8	8	75.05	8.26	49.94	12.72	14.00	14.40	12.93

Notation

The following symbols are used in this paper:

A, B, C, D, E = regression coefficients of the linear model;
b = street or open-channel width;
F = Froude number = $V/\sqrt{gy}$;
F_{ix} = Froude number of the inflow in the x-direction;
g = gravitational acceleration;
h = weir height at the output of the experimental setup;
k_s = effective surface roughness height;
l = characteristic length of flow;
Q = discharge;
Q_{ix}/Q_T = inflow ratio in x-direction;
R = Reynolds number = Vy/ν;
V = average flow velocity;

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y = average flow depth; and
ν = kinematic viscosity.

Subscripts

i = inflow;
o = outflow;
w = weir; and
x, y = coordinate axes.

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