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Short Communication

Analysis of flow through lateral rectangular orifices in open channels

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ABSTRACT

A side lateral orifice in open channel is hydraulic control structure widely used in hydraulic, irrigation and environmental engineering for diverting the flow from main channel to a secondary channel. In this paper, analytical relationships for the discharge through side orifice are developed accounting for the pressure distribution over the area of the orifice. The computed discharges using the proposed relationship are within $\pm 5\%$ of the observed values; however percentage error is more in case the discharge is computed using earlier equations.

1. Introduction

Side orifices are used to divert flow from main channel to secondary channels and widely used in hydraulic, environmental and irrigation engineering. The flow is diverted from a channel to different fields through prescribed side orifices for the irrigation purpose. In water and wastewater treatment plants, side orifices are often used to distribute incoming flow to parallel process units such as flocculation basins, sedimentation tanks, and aeration basins [14]. The mechanics of flow through a single orifice located in the side of open channels have been studied by many researchers. Detailed study on side rectangular orifice or slot has been carried out by Gill [4], Ramamurthy et al. [14], Ojha and Subbaiah [12] and Hussain et al. [8]. Hussain et al. [7] carried out an experimental study on side circular orifice and highlighted a discharge equation. Other than side slot or side orifice, side sluice gate and side weir are used to divert the flow from main channel to a secondary channel. Studies on such devices are extensively reported in literature [13,1,9,5,15].

Ramamurthy et al. [14] derived an expression for the flow through a rectangular side orifice discharging from a rectangular channel. Fig. 1 shows a typical sketch of the side orifice in an open channel. They considered the velocity of jet V_j issuing out from the orifice as resultant of the velocity in the channel V_1 and velocity normal to the channel due to static head H and expressed discharge through orifice as

$$Q=\int_{H_2}^{H_1} C_d V_j L dH \tag{1}$$

where $V_j=\sqrt{V_1^2+2gH}$; $H_1=Y_m-W$; and $H_2=Y_m-W-b$

Here H_1 is the head above the lower crest of the orifice; H_2 is the head above the upper crest of the orifice; C_d is the coefficient of discharge; L is the width of the rectangular orifice; b is the height of the rectangular orifice; Y_m is the depth of flow in the main channel; g is the acceleration due to gravity and W is sill height. They used the following equation for the coefficient of discharge [3]:

$$C_d=0.611+C_1\eta^2+C_2\eta^4+C_3\eta^6 \tag{2}$$

where velocity ratio

$$\eta=\frac{V_1}{V_j}=\frac{V_1}{\sqrt{V_1^2+2gH}} \tag{3}$$

and

$$C_1=0.254\left(\frac{L}{B}\right)-0.538;\quad C_2=0.234\left(\frac{L}{B}\right)+0.058;$$
$$C_3=-0.489\left(\frac{L}{B}\right)-0.129 \tag{4}$$

where B is the width of the channel.

Using Eqs. 1–4, they derived the following relation for the discharge through the orifice:

$$Q=\frac{V_1^3 L}{g}\left[f\left(\eta_1,\frac{L}{B}\right)-f\left(\eta_2,\frac{L}{B}\right)\right] \tag{5}$$

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Nomenclature

B	width of the main channel, m
C_d	coefficient of discharge
g	acceleration due to gravity, m/s^2
H	head over the elemental strip, dH
H_2	head over the upper crest of the orifice, m
H_1	head over the lower crest of the orifice, m
L	width of rectangular orifice, m
b	height of rectangular orifice, m
Q	discharge through the orifice, m^3/s
Q_m	discharge in the main channel, m^3/s
V_1	velocity in the main channel, m/s
V_j	jet velocity, m/s
$\vec{A}$	area vector of side orifice
V	velocity normal to the approach flow in the main channel, m/s
W	sill height, m
Y_m	depth of approach flow in the main channel, m

where

$$f\left(\eta_1,\frac{L}{B}\right)=(1-\eta_1^3)\left(\frac{C_3}{3}+\frac{0.611}{3\eta_1^3}\right)+(1-\eta_1)\left(\frac{C_1}{\eta_1}+C_2\right) \tag{6}$$

and

$$f\left(\eta_2,\frac{L}{B}\right)=(1-\eta_2^3)\left(\frac{C_3}{3}+\frac{0.611}{3\eta_2^3}\right)+(1-\eta_2)\left(\frac{C_1}{\eta_2}+C_2\right) \tag{7}$$

Considering that the velocity of the upper layers will be higher than mean velocity V_1, Ramamurthy et al. [14] introduced a flow reduction factor 0.95 in discharge computation which partly accounts for the effect of non-uniform velocity distribution,

$$Q=0.95\frac{V_1^3L}{g}\left[f\left(\eta_1,\frac{L}{B}\right)-f\left(\eta_2,\frac{L}{B}\right)\right] \tag{8}$$

The assumptions made in deriving the above discharge equation were that the channel is horizontal and the flow is subcritical. The validity of Eq. (8) was checked by [8] using experimental data collected on square side orifices of size L=0.044 m, 0.089 m and 0.133 m in an open channel of 9.15 m length, 0.50 m width and 0.60 m depth. The crest heights of the orifices were at 0.5, 0.10, 0.15 and 0.20 m. They have used ultrasonic flow meter for the calibration of weir used for measuring discharge from the side orifice and main channel. They reported that the Ramamurthy et al. [14] equation underestimates the discharge as shown in Fig. 2. This could be due to erroneous formulation of Eq. (1) where angle between the area and velocity vectors are not taken into consideration. The present paper deals with analytical consideration of discharge equation for the side orifices with due consideration of directions of velocity and area vector while computing the discharge i.e., $Q=\vec{V}\,\vec{A}$.

2. Analytical consideration

Considering varying pressure head over the flow area of a lateral rectangular orifice of size L fitted in the side of an open channel at sill height W, discharge through the lateral orifice may be written as

$$Q=\int_{H_2}^{H_1} C_dVLdH \tag{9}$$

$$Q=\int_{H_2}^{H_1} C_d\sqrt{2gH}LdH \tag{10}$$

Substitution of Eqs. (2) and (3) into Eq. (10) yields

$$Q=0.611L\sqrt{2g}\int_{H_2}^{H_1}H^{1/2}\,dH+C_1L\sqrt{2g}\int_{H_2}^{H_1}\frac{V_1^2}{(V_1^2+2gH)}H^{1/2}\,dH$$
$$+C_2L\sqrt{2g}\int_{H_2}^{H_1}\frac{V_1^4}{(V_1^2+2gH)^2}H^{1/2}\,dH+C_3L\sqrt{2g}\int_{H_2}^{H_1}\frac{V_1^6}{(V_1^2+2gH)^3}H^{1/2}\,dH \tag{11}$$

After the integration of the terms on the right hand side of Eq. (11), it may be written as

$$Q=I_1+I_2+I_3+I_4 \tag{12}$$

where

$$I_1=0.407L\sqrt{2g}(H_1^{3/2}-H_2^{3/2}) \tag{13}$$

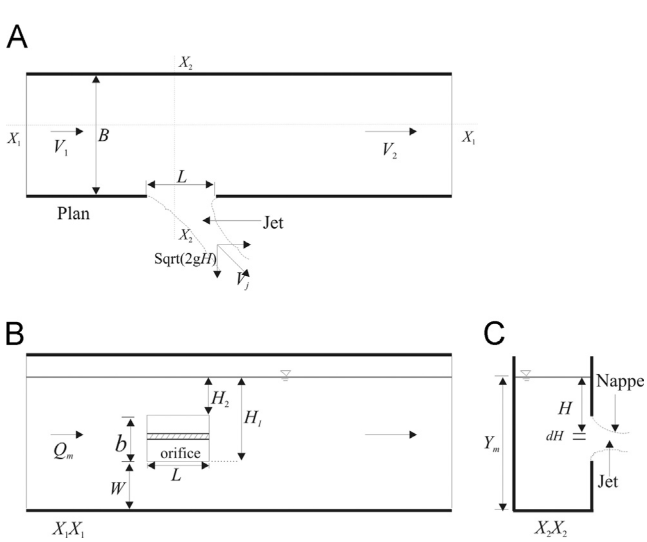

Fig. 1. Lateral orifice model (A) Plan; (B) X_1-X_1 View and (C) X_2-X_2 View.

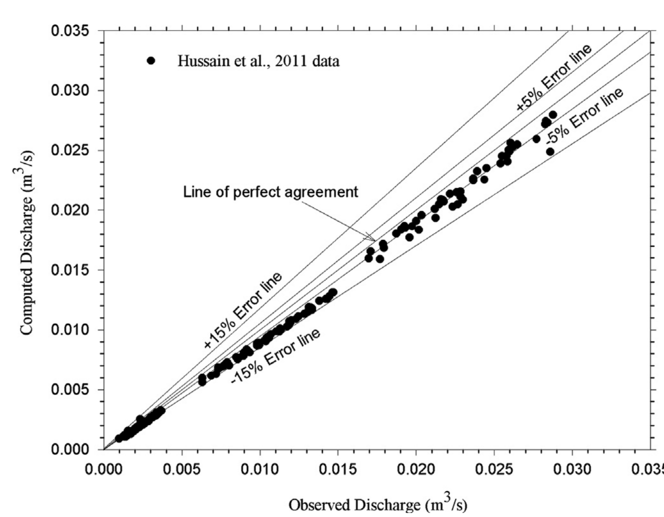

Fig. 2. Comparison of computed discharge from Ramamurthy et al. [14] equation with observed values from Hussain et al. [8] data.