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Discharge coefficient of compound triangular–rectangular sharp-crested side weirs in subcritical flow conditions

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ABSTRACT

Side weirs are among the important hydraulic structures for flow diversion in flood schemes or sewer networks. Side weirs are generally rectangular or triangular in shape and have a limitation for precise measurement of low and high flow. Therefore compound side weirs are suggested for accurate flow measurement in a wide range of discharges. In this study, the discharge coefficient of compound sharp-crested side weir consisting of rectangular and triangular part was studied experimentally. The results are in agree with previous study which show the discharge coefficient of a compound side weir is a function of the upstream Froude number ((Fr_1), the ratio of weighted crest height of the weir to upstream water depth $(\bar{w}/y_1)$ and the ratio of weir length to upstream water depth (L/y_1). Based on the experimental data and regression modeling, a dimensionless equation has been developed for estimation of the discharge coefficient and two equations have been proposed for estimation of flow discharge in compound triangular–rectangular sharp-crested side weirs. The results also show that there is a good agreement between estimated and measured data.

1. Introduction

Side weirs have been extensively used in hydraulic and environmental engineering applications. They play a substantial role in distribution channels of irrigation systems and water and wastewater treatment plants. Side weirs are also used as an emergency structure in many hydraulic structures. The side weir is normally installed at one side of a channel to divert flow laterally. Nadesamoorthy and Thomson [16], Subramanya and Awasthy [20], Yu-Tek [23], Ranga Raju et al. [18], Hager [10], Cheong [3], Singh et al. [19], Swamee et al. [21], Jalili et al. [12], Ghodsian [7], Borghei et al. [1,2], and Emiroglu et al. [6] presented equations for discharge coefficients of rectangular, sharp-crested side weirs based on experimental results. Kumar and Pathak [14] and Ghodsian [9] also presented equations for discharge coefficients of triangular sharp-crested side weirs based on experimental results. Swamee et al. [21] used an elementary analysis approach to estimate the discharge coefficient in smooth side weirs through an elementary strip along the side weirs. Ghodsian [8] studied behavior of rectangular side weir under supercritical flow conditions. These types of weirs are generally rectangular or triangular in shape and have a limitation in cases where there is a need to divert flow discharges varying from low to high water levels. Furthermore, for relatively small flows, the notch of a rectangular weir must be very narrow so that head over weir is not too small (otherwise the nappe clings to the downstream side of the plate). Also for the same maximum capacity, it can measure much smaller discharges in triangular weir in compare with a rectangular weir. In practical engineering, a compound weir composed of rectangular and/or triangular parts in the shape of cross section is also a common device for flow control in canals and mountainous gullies [15].

Some researchers have studied flow hydraulics in compound normal weirs, which are built across the channel. The first of them is USBR [22] and the most recent of them are Martinez et al. [15] and Piratheepan et al., [17]; their work describes the design and calibration of a compound normal sharp-crested weir consisting of two triangular parts with different notch angles. They supposed that, by linearly combining the discharge relations of triangular and rectangular sharp-crested weirs, the theoretical discharge equations for compound sharp-crested weirs would be reasonable. Jan et al. [13] provide more experimental data on different shapes of compound weirs. According to these studies, a power equation and a theoretical approach based on linear combinations of simple weir equations have been presented for prediction of flow discharge over compound normal weirs.

Zahiri et al. [24] studied the discharge coefficient of compound

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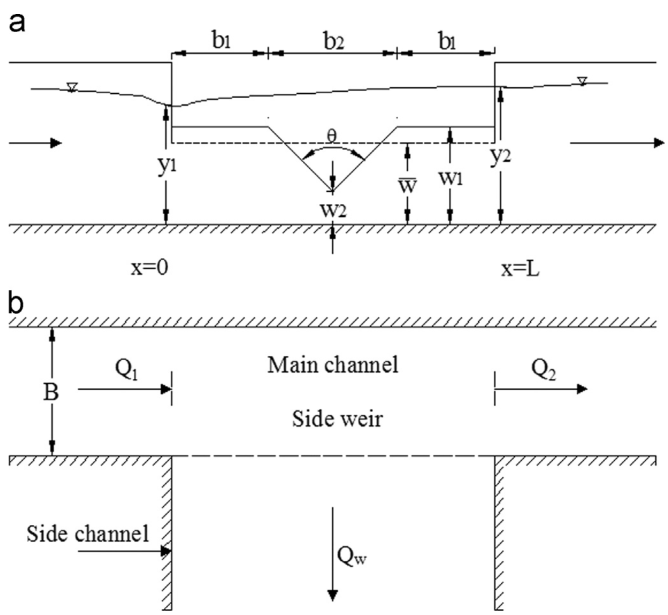

Fig. 1. The schematic of CTRS side weirs.

rectangular sharp-crested side weirs, experimentally. The objective of their research was to evaluate the reliability of existing simple side weir equations and introduced an equation to estimate the discharge coefficient of compound rectangular sharp-crested side weirs. They found that the discharge coefficient of compound side weirs has a high correlation with three dimensionless parameters including upstream Froude number (Fr_1), ratio of weighted weir height to upstream flow depth ($\bar{w}/y_1$) and the ratio of weir length to upstream flow depth (L/y_1).

Looking at literatures shows that there is lack of information on compound side weirs. The present study conducted laboratory experiments on free flow over side weirs that are composed of triangular–rectangular weir (Fig. 1). The lower weir is suitable for diversion and measurement of low-flow discharges, while the upper sections are appropriate for high-flow discharges. The main advantage of this special kind of side weir is that overflow discharges are measured and regulated with a reasonable sensitivity over wide flow ranges.

This study aims to develop a global discharge coefficient for compound triangular–rectangular sharp crested side weir (CTRS) and to evaluate the suitability of the linear combination of traditional discharge relations of simple weirs to describe the discharge relations for the corresponding weirs.

2. Laboratory experiments

Experiments were carried out in the Hydraulic Laboratory of Shahrood University, Shahrood, Iran. A schematic representation of the experimental set-up is shown in Fig. 2. The experimental set-up consists of a main channel and a discharge collection channel. The main channel was 10 m long and the bed had a rectangular cross section. The main channel was 0.6 m wide, 0.6 m deep. The channel consisted of a smooth horizontal well-painted steel bed with a vertical glass sidewall. A sluice gate was fitted at the end of the main channel in order to control flow depth. The collection channel was 1 m wide and 0.5 m deep, and connected to the main channel. An Asimeto brand digital point gauge with ± 0.01 m sensitivity was fitted 1 m from the weir. The side weirs were fabricated from steel plates with 2 m thickness, which were sharp-edged and fully aerated and installed flush with the main channel bank.

Fig. 2. Experimental setup.

Water for the main channel was supplied through a supply pipe from a sump and the flow was controlled by a gate valve. In this study, the flow rate was between 50 and 110 l/s and was measured by means of a calibrated ultrasonic flowmeter (± 0.01 L/s sensitivity) installed on the supply line. The overflow rate at the side weir was obtained by a calibrated 90° V-notched weir, located at the downstream end of the collection channel (Q_w).Water depth was measured using the point gauge at the side weir region, along the channel centerline and close to side weirs. The geometry of different compound side weirs are presented in Table 1.

3. Basic theory

The conservation of energy principle is used for the analysis of spatially varied flow with decreasing discharge. The dynamic equation of spatially varied flow for outflow over a weir was given by Henderson [11] as

$$\frac{dy}{dx} = \frac{S_0 - S_f - \left(\frac{\alpha Q}{gA^2}\right)\cdot\left(\frac{dQ}{dx}\right)}{1 - \left(\frac{\alpha Q^2 B}{gA^3}\right)} \tag{1}$$

where y is the depth of flow in main channel (variable in the direction of flow); x is the longitudinal direction; S_0 is the main channel slope; S_f is the friction slope; α is the kinetic energy correction factor; A is the cross-sectional area of flow; g is acceleration due to gravity; and B is the channel width.

The general equation of rectangular weirs can be written as follows [5]:

$$q = -\left(\frac{dQ}{dx}\right) = -\left(\frac{dQ_w}{dx}\right) = \frac{2}{3}C_m\sqrt{2g}\,(y - w)^{1.5} \tag{2}$$

Table 1
The range of variables used in CTRS side weirs.

Variable	Source	
	Section 1	Section 2
Q_1 (l/s)	50–110	50–110
Fr_1	0.16–0.7	0.16–0.7
$w1$ (cm)	15, 17, 19, 21	15, 17, 19, 21
$w2$ (cm)	3, 5, 7, 9	3, 5, 7, 9
$b1$ (cm)	10.75–28.1	4–23
$b2$ (cm)	11.55–18.5	20–32
L (cm)	40, 50, 60, 70	40, 50, 60, 70
θ (degree)	60	90