Flow Measurement and Instrumentation 41 (2015) 50–56

Contents lists available at ScienceDirect

Flow Measurement and Instrumentation

journal homepage: www.elsevier.com/locate/flowmeasinst

Weir velocity formulation for sharp-crested rectangular weirs

S. Gharahjeh*, I. Aydin, A.B. Altan-Sakarya

Department of Civil Engineering, Middle East Technical University, Ankara 06800, Turkey

ARTICLE INFO

Article history:
Received 1 October 2013
Received in revised form
24 October 2014
Accepted 29 October 2014
Available online 8 November 2014

Keywords:
Flow measurement
Discharge
Sharp-crested weirs
Rectangular weir
Open-channel flow

ABSTRACT

Discharge in open channels can be measured by sharp-crested rectangular weirs. Generally, measured head over the weir crest is substituted into an empirical formula derived from energy considerations to calculate the discharge. Assumptions made on the derivation are taken into account by defining a discharge coefficient that fits into the experimental data. In this study, a physical quantity, the average velocity over the weir section defined as 'weir velocity' is directly formulated as function of weir geometry and head over the weir. Weir velocity plotted against the weir head has a universal behavior for constant weir width to channel width ratio independent of the weir size. This unique behavior is described in terms of weir parameters to calculate the discharge without involving a discharge coefficient. Combining weir velocity data for variable weir widths provides a basis for direct formulation of discharge. The weir velocity exhibits simpler functional dependency on weir parameters in contrast to the discharge coefficient.

1. Introduction

Sharp crested rectangular weirs are designed as control sections to provide a particular link between the discharge and water depth. The depth at a section upstream of the weir is measured and the discharge is calculated. These classical devices are commonly utilized in laboratories, irrigation practices and industry.

Three-dimensional flow phenomena involving significantly curved streamlines and vortex structures can take place around the weir plate. Due to this complex nature of the flow over the weir, any analytical derivation for the flow rate entails simplifying assumptions and requires complementary functions established by utilizing experimental data. Most of the weir formulations involve a discharge coefficient to complement the discharge expression obtained from energy considerations.

For a rectangular weir (Fig. 1) the discharge, Q, may be written in terms of the measured head over the weir, h, the weir width, b and the discharge coefficient, C_d [6]:

$$Q = \frac{2}{3} C_d \sqrt{2g}\, b h^{3/2} \tag{1}$$

where g is the gravitational acceleration. The discharge coefficient is assumed to represent all effects due to assumptions made in the derivation of Eq. (1). Therefore, C_d may be expected to depend on the channel width, B, the weir height, P and dimensionless parameters such as Reynolds number, R_e, Weber number, W_e and Froude number, F_r. It is possible to set limitations on the working range of Eq. (1) to eliminate such dependencies.

Many researchers have studied weirs to determine the discharge coefficient, C_d. Their findings are either empirical or analytical and sometimes a combination of both. Some of the available C_d formulations in the literature are presented in Table 1.

One of the oldest experimental researches is traced back to Rehbock [11]. He proposed a relation for C_d which is derived with neglecting viscous and capillary effects.

Swamee [13] suggested a full-range weir equation by combining the proposed equations of Rehbock [11] and Rouse [12] and fitting the experimental data of Kandaswamy and Rouse [9]. The resulting equation would hold good for extreme variations of head over weir height ratios (h/P). It can be applied to sharp-crested, narrow-crested, broad-crested and long-crested weirs. Another study on sharp crested weirs was presented by Bagheri and Heidarpour [4] based on integration of velocity due to free-vortex motion assumed between the upper and lower nappe profiles. Form of the discharge coefficient expression was obtained from the best fit approximations of the measured nappe profiles. For the range of $0 < h/P < 9$, Bagheri and Heidarpour [5] revised their equation by enlarging the data base and extended the validity range to $0 < h/P < 10$. Aydin et al. [1] introduced the slit weir suitable for measuring small discharges with high accuracy due to increased head over the weir. The most important characteristic of the slit weir is the independency of the discharge coefficient from the channel width, B, because of the completely contracted nature of the flow over the weir. Formulation of the discharge coefficient was improved with increased data range in a later study by Aydin et al. [2]. Although the measuring capacity for large discharges is limited, the precision and reliability achieved by the slit weir is significant when compared to other weir types.

---

* Corresponding author.

http://dx.doi.org/10.1016/j.flowmeasinst.2014.10.018
0955-5986/

In a recent study by Aydin et al. [3], weir velocity concept was introduced. According to this study, using weir velocity instead of discharge coefficient can lead to a more realistic and accurate calculation of discharge in rectangular weirs. Since weir velocity has a universal distribution pattern, discharge can better be formulated in terms of average weir velocity which can easily be fit empirically. The experimental investigation was focused on the applicability of various formulations for discharge to free the discharge relation from C_d. The average weir velocity concept was introduced and the discharge relation was written in terms of weir velocity:

$$Q = V_w(bh) \tag{2}$$

A best fit function for the weir velocity was proposed based on the experimental data. Also the discharge relation was divided into two parts, partially and fully contracted (slit) weirs. Partially contracted weirs cover the range of $0.25 < b/B \le 1$ and slit weirs fall in the range of $b/B \le 0.25$ for which separate discharge relations based on weir velocity have been given.

In the present study, a comprehensive experimental study is conducted to investigate the hydraulics of flow over sharp crested weir plates. Data from previous studies is also utilized either to complete the working range or to compare the present developments. Complete range of rectangular weirs from full width to completely contracted slit weir were exploited to illustrate the appropriate weir dimensions and safe use of weirs within acceptable accuracy range. Compact expressions for the weir velocity, valid for higher weir heads, were investigated making use of regression analysis.

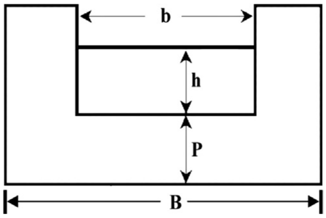

Fig. 1. Front view of the weir plate.

2. Experimental setup and procedures

The experimental setup [8] is made up of Plexiglas consisting of a 6 m long rectangular channel with a width of 32 cm and a depth of 70 cm. The weir plate is 1 cm thick and the beveled edges of the weir plate are 2 mm thick all around the working section. There is a tank underneath the channel exit where water is temporarily collected for volumetric measurement. Its cross-sectional area is 1 m^2. Water is supplied from upstream entrance through a pipe. The discharge in the channel is controlled by a valve before it reaches the entrance tank. At the end of the entrance tank there are several vertical parallel screens which are meant to subside the fluctuations generated at the water surface. After the entrance, water passes through a rectangular channel and exits over the weir down into the measurement tank and this circulation continues.

Influences from the channel bed and side walls should be eliminated by contracting the weir section. For this reason, in this research, after performing a number of experiments on different weir heights, it was concluded that weir height value ought to be kept fixed at 10 cm to avoid boundary layer influence on the flow over the weir. The same result was obtained and presented in Aydin et al. [3] confirming the lower limit suggested by Bos [6] also. It is concluded that any P greater than the recommended value will hydraulically imply the flow over the weir to be independent of the

Table 1
Discharge coefficients proposed in different studies.

Proposed by:	Discharge coefficients, C_d	Remarks:
Rehbock [11]	$0.611+0.08(h/P)$	$h/P \le 5$ m $\le P \le 1.0$ m 0.025 m $\le h \le 0.6$ m
French [7]	$\frac{0.611+2.23(B/b-1)^{0.7}}{1+3.8(B/b-1)^{0.7}}+\frac{0.075-0.011(B/b-1)^{1.46}}{1+4.8(B/b-1)^{1.46}}\frac{h}{P}$	Contracted sharp crested rectangular weirs
Swamee [13]	$1.06\left\{\left(\frac{14.14P}{8.15P+h}\right)^{10}+\left(\frac{h}{h+P}\right)^{15}+1.834\left[1+0.2\left(\frac{\left(\frac{h}{L}\right)^5+1500\left(\frac{h}{L}\right)^{13}}{1+1000\left(\frac{h}{L}\right)^3}\right)^{0.1}\right]^{-10}\right\}^{-0.1}$	All types of rectangular weirs irrespective of variation of h/P or h/b ratio
Bagheri and Heidarpour [4]	$0.324\ \exp\ [0.94\,(b/B)]\ \ln\left[1+\frac{0.73(h/P)+3.64}{\exp(1.18\ b/B)}\right]$	$0 < h/P < 9$
Aydin et al. [2]	$0.562+\frac{10\left\{1-\exp\left[-(2h/b)^2\right]\right\}^{-1}}{R_e{}^{0.45}}$	$B \ge 4b$ $P \ge 0.04$ m

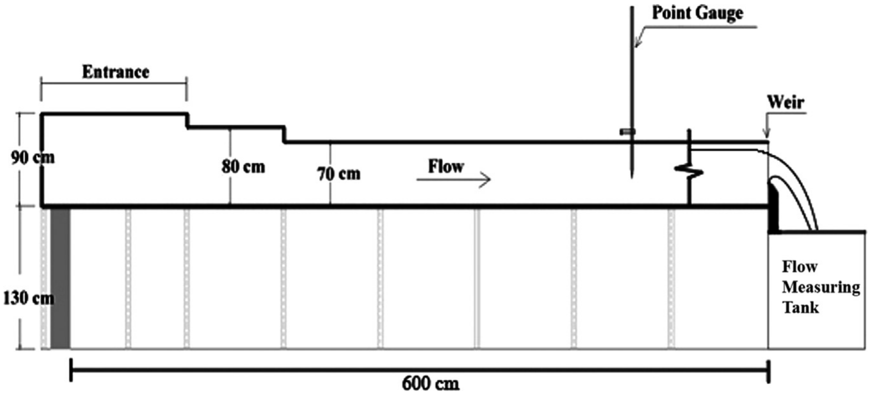

Fig. 2. Schematic profile view of the setup.