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Research Article

Discharge Coefficient of Semicircular-Trapezoidal Weir

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ABSTRACT

Weirs are widely used to regulate the flow of rivers and open channels. The aim of this study is to enhance the discharge coefficient in trapezoidal weir. Some experiments were performed in combination of semicircular and equivalent trapezoidal weirs. A linear equation was presented for calculating the compound semicircular-trapezoidal weir. Optimization method was used to determine the best fit coefficient of the equation. The results showed that discharge coefficient of the semicircular-trapezoidal weir increases up to 40 percent. Values of R^2 and RMSE for equation of the semicircular-trapezoidal weir are obtained 0.9982 and 0.0003, respectively. It seems that by combining suitable cross sections and specifying optimum shapes, discharge coefficient for these structures can be significantly increased.

Key words: Best hydraulic section, Optimization, Trapezoidal, Water depth

INTRODUCTION

Weirs are widely used to regulate river flow and open channels and measure the flow discharge. Broad-crested, sharp-crested, cylindrical-crested, and ogee weirs are the most common types of weirs. In sharp-crested wires, water flow passing the crown falls down the weir without any contact with down plate. Sharp-crested weirs are utilized when accurate measurement of the discharge is needed (Bos, 1989; USBR, 1997).

Although much research has been done on sharp-crested weirs, there are few studies that have focused on the compound sharp-crested weirs. In compound weirs, feature of different sections are combined. Various weirs of modified sections have been suggested in the past to enhance their discharging capacity. Compound weir consists of the triangular (on the bottom) and rectangular (on the top) sections which named trapezoidal weir has some advantages like controlling the upstream level particularly in low flows, precise measurement in low flows and high capacity for great flows (Ramamurthy and Vo, 1993). French as a pioneer (1985) presented equation (1) to calculate discharge coefficient for compound trapezoidal sharp-crested weirs:

$$Q = \frac{2}{3} C_d \sqrt{2g} (bH^{3/2} + \frac{4}{5} tg(\frac{\theta}{2}) H^{5/2}) \quad (1)$$

Where Q is discharge (m^3/s), C_d is discharge coefficient, g is gravity acceleration which equals 9.81 (m/s^2), H is water head (m) on the weir, b is the length of crest (m) and θ is the angle of opening. In this equation, to consider the effect of contraction due to trapezoidal shape and to lessen the error caused by contraction, 0.2H is subtracted from the length of weir on the right side.

Abbaspour (2001) investigated flow on a compound triangular-rectangular sharp-crested weir with 90^o angle both contracted and suppressed. Results showed that discharge coefficient increases by increasing water head on the upstream. Also, aeration in compound contracted weir does not have positive effect on flow capacity.

Martinez *et al.* (2006) showed that the discharge coefficient increases by raising the effective head on the weir for different openings in the center of a triangular-triangular weir. Calculated and experimental discharge had neglect able difference. Chyan-Deng *et al.* (2009) investigated the discharge coefficient on compound broad crest weirs. Four types of compound broad crest weirs were included rectangular-rectangular (Figure 1a), rectangular-trapezoidal (Figure 1b), triangular-rectangular (Figure 1c), and trapezoidal-triangular (Figure 1d). A linear equation is used to determine the discharge of trapezoidal, triangular and rectangular broad crest weirs. Results indicate that there is a maximum 3 percent different between theoretical and measured discharge

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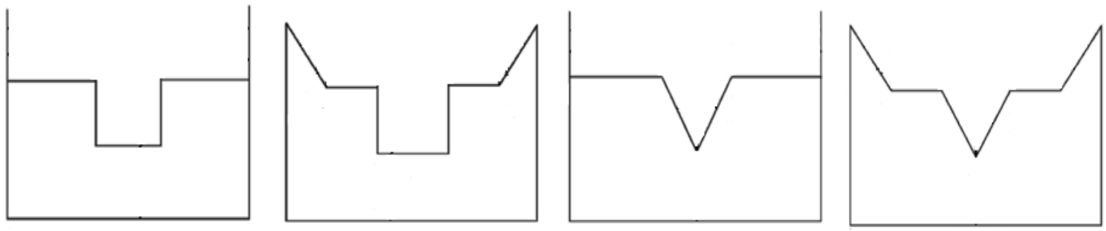
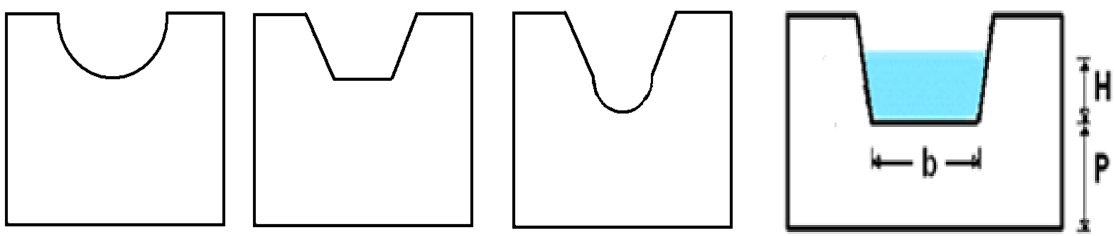


a: Rectangular-rectangular **b:** Rectangular-trapezoidal **c:** Triangular-rectangular **d:** Triangular-trapezoidal

Fig. 1: Four types of compound broad crest weirs CTTBC (Chyan-Deng *et al*., 2009)



a: Semicircular, trapezoidal and compound semicircular-trapezoidal weir **b:** Parameters of trapezoidal weir

Fig. 2: Parameters of trapezoidal weir **(a)** and scheme of the semicircular, trapezoidal and compound semicircular-trapezoidal weir **(b)**

which means the linear equation is a suitable estimation for compound broad crest weirs.

Poureskandar *et al*. (2010a) studied effect of flow characteristics on discharge coefficient in a compound rectangular-rectangular broad crest weir. The weir with different sizes of central width, crest length and height were studied. Results showed that discharge coefficient increase significantly by increasing the ratio of water head to length of weir.

Trapezoidal weirs are commonly used in most irrigation open channels and circular sewage channels due to their simplicity in design and performance. In addition, circular weirs are the best hydraulic section. In these weirs, various factors like height of weir, side contraction, upstream water head and tail water depth effect on the capacity of discharge flowing over the compound sharp-crested weirs.

In this study, trapezoidal and semicircular weirs were compounded and a new compound semicircular-trapezoidal weir was introduced. The aim of this research is to investigate experimentally the discharge coefficient of compound semicircular-trapezoidal weir and develop an experimental-mathematical method to calculate the discharge in semicircular-trapezoidal weir.

MATERIALS AND METHODS

Experiments were carried out in a metal-glass flume at the Hydraulic Laboratory of Water Engineering Department, University of Tabriz. The horizontal-rectangular flume was 6 m long, 0.25 width and 0.5 depth. Flow was supplied from a constant head tank and a pre-calibrated sharp-crested triangular weir was used to flow measurements at the end of the channel.

The experiments were done on the semicircular, trapezoidal and compound semicircular-trapezoidal weirs to evaluate and compare the discharge coefficient of the weirs. Figure (2a) shows schematic of the weirs used in this research. The weir plates were made of 10 mm thick plexiglass. The water depth (H) was measured at a section 0.4 m upstream of the structure by a point gauge having an accuracy of 0.1 mm. All the experiments were conducted under free flow conditions. Figure (2b) illustrates parameters of a common trapezoidal sharp crested weir. In this figure, H is the water depth over the weir, b is bottom width, P is height of weir.

In a semicircular weir with best hydraulic section and a trapezoidal weir, assuming the water surfaces of semicircular and trapezoidal weirs are equal, following condition is fulfilled:

$$b + 2my = 2y \quad \Rightarrow \quad b = 2y(1-m) \Rightarrow \frac{b}{y} = 2(1-m) \tag{2}$$

And assuming the cross sections of semicircular and trapezoidal weirs are equal as:

$$(b+my)y = \tfrac{\pi}{2}y^2 \quad \Rightarrow \quad b+my = \tfrac{\pi}{2}y \quad \Rightarrow \quad b = (\tfrac{\pi}{2}-m)y \Rightarrow \frac{b}{y} = \tfrac{\pi}{2}-m \tag{3}$$

Combining equations (2) and (3), parameter m is determined for an equivalent trapezoidal weir as:

$$2(1-m) = \tfrac{\pi}{2} - m \qquad \Rightarrow \qquad m = 2 - \tfrac{\pi}{2} \tag{4}$$

In this research, the trapezoidal and semicircular-trapezoidal weirs were constructed based on the parameter m (equation 4).

Equations of weirs

Trapezoidal sharp-crested weir

Trapezoidal weir is a compound weir consists of the rectangular and triangular weirs. The discharge equation of the weir is as:

$$Q = \frac{2}{3}C_d\sqrt{2g}(bH^{3/2} + \frac{4}{5}tg(\frac{\theta}{2})H^{5/2}) \tag{5}$$

$$\alpha = \frac{2}{3}\sqrt{2g}\,(bH^{3/2} + \frac{4}{5}tg(\frac{\theta}{2})H^{5/2}) \qquad (6)$$

Finally:

$$Q = C_d\alpha \qquad (7)$$

Semicircular sharp-crested weir

Discharge equation of a semicircular weir is as (Panuzio and Ramponi, 1936):

$$Q = C_d F^* D^{2.5} \qquad (8)$$

$$\beta = F^* D^{2.5} \qquad (9)$$

Finally:

$$Q = C_d\beta \qquad (10)$$

Where D is the diameter of circle, $F^* = \frac{4}{15}\sqrt{2g}\,F$ and

$$F = \sqrt{1 - \frac{H}{D}(3(\frac{H}{D})^2 - (\frac{H}{D}) - 2) + 2}$$

Compound semicircular-trapezoidal sharp-crested weir

This compound weir is consisting of a trapezoidal and a semicircular weir. The fundamental hypothesis is that the circular part of the weir is always full and there are water level variations only in the trapezoidal section. By gathering the equations (5) and (8), discharge equation of the weir is given as:

$$Q = \frac{2}{3}C_d\sqrt{2g}(bH^{3/2} + \frac{4}{5}tg(\frac{\theta}{2})H^{5/2}) + C_d F^* D^{2.5} \qquad (11)$$

In this equation, parameters μ is defined as following:

$$\mu = \frac{2}{3}\sqrt{2g}(b\,H^{3/2} + \frac{4}{5}tg(\frac{\theta}{2})H^{5/2}) + F^* D^{2.5} \qquad (12)$$

Finally, equation (11) is simplified using equation (12) as:

$$Q = C_d\mu \qquad (13)$$

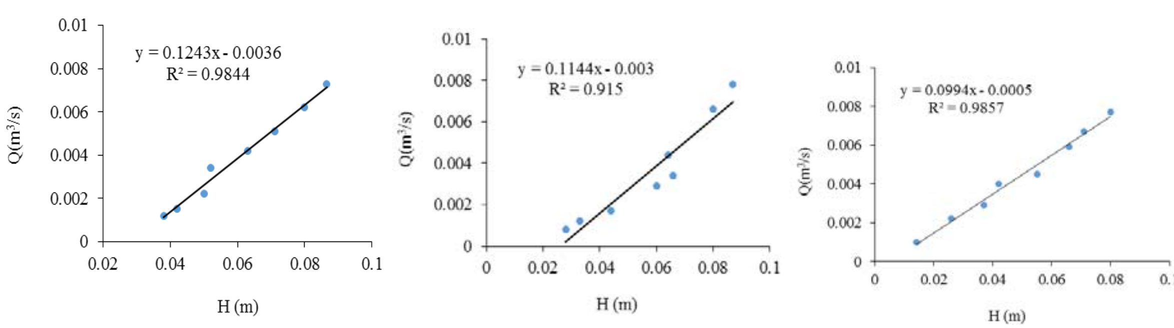
In each weir, parameters α, β and μ were computed using equations (6), (9) and (12), respectively. Then, equations (7), (10) and (13) were used to calculate the discharge coefficient in trapezoidal, semicircular and semicircular-trapezoidal weir, respectively. Optimization method was used to determine the discharge coefficient and the best fit coefficient is obtained. Optimization method was done in Microsoft EXCEL.

RESULTS AND DISCUSSION

Flow discharge (Q) versus water depth (H) values of the trapezoidal weir (a), semicircular weir (b) and semicircular-trapezoidal weir (c) are given in Fig. 3. This figure indicates that discharge increases almost linearly with the increase of the head over the weirs. Studies conducted by Kumar *et al.* (2011), Pooreskandar *et al.* (2010b) reported a linear relationship between discharge (Q) and head over the weir (H) in low values of discharge.

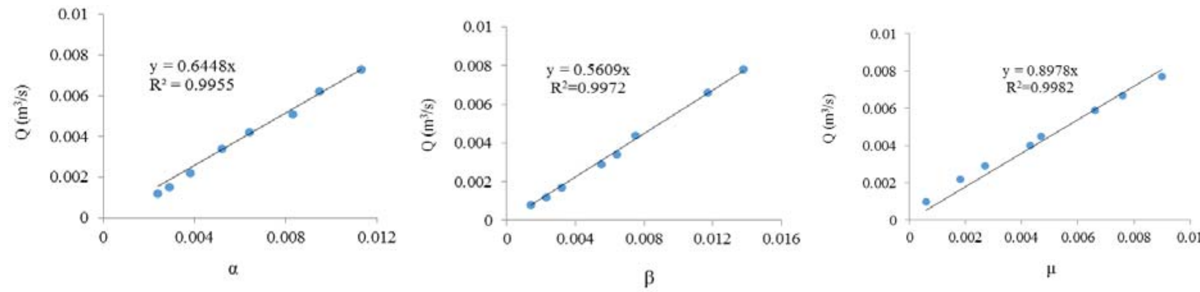
Figure (4) shows variation of Q versus parameters α, β and μ for trapezoidal, semicircular and compound semicircular-trapezoidal weirs, respectively. By performing optimization, the best fit coefficient is obtained for equations (7), (10) and (13). As shown in the Figure (4), discharge coefficients of the weirs are 0.6448, 0.5609 and 0.8978 for trapezoidal, semicircular and semicircular-trapezoidal weirs, respectively. Discharge coefficient of trapezoidal and semicircular-trapezoidal weirs with respect to the semicircular weir increased 15% and 60%, respectively. Discharge coefficient of the semicircular- trapezoidal weir (fig. 4c) increased 40% by combing trapezoidal and semicircular weirs.

The equations (7), (10) and (13) are used to compare of the measured and calculated discharges is shown in figure (5). As shown in the figure, there is a well agreement between computed discharges and measured ones. Root mean square error (RMSE) of equations (7), (10) and (13) are 0.0002, 0.0001 and 0.0003 m^3/s, respectively. It can be seen that the semicircular-trapezoidal weir equation can depict the discharge as well as the other weirs.



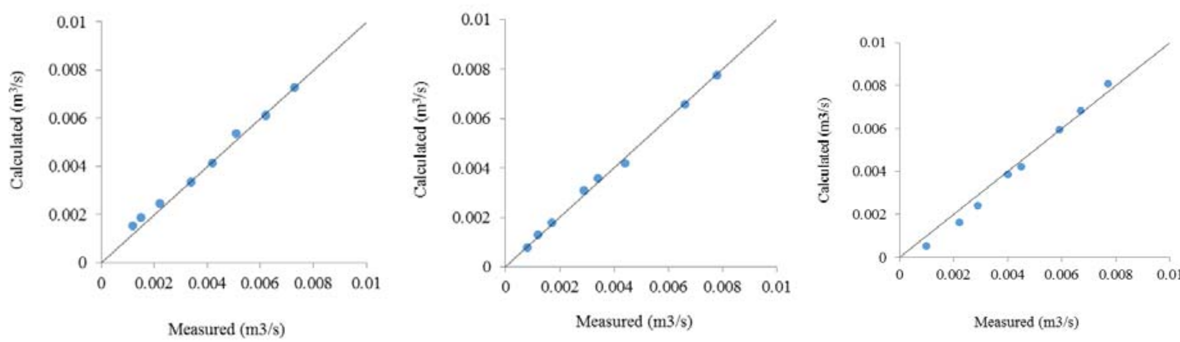
a) Trapezoidal weir **b)** Semicircular weir **C)** Semicircular-trapezoidal weir

Fig. 3: Discharge (Q) versus and water depth (H) in the trapezoidal (a), semicircular (b) and semicircular-trapezoidal (c) weir



a) Trapezoidal weir **b)** Semicircular weir **C)** Semicircular-trapezoidal weir

Fig. 4: Discharge (Q) values versus parameter α in the trapezoidal (a), β in the semicircular (b) and μ in semicircular-trapezoidal weir



a) Trapezoidal weir **b)** Semicircular weir **C)** Semicircular-trapezoidal weir

Fig. 5: Calculated versus measured discharges in the trapezoidal (a), semicircular (b) and semicircular-trapezoidal (c) weir

Conclusions

An experimental study was carried out to enhance the discharging capacity of a sharp crested weir by combining an equivalent trapezoidal and semicircular weir. Results showed discharge coefficient of compound weir increases 40%. In the semicircular- trapezoidal weir, energy loss decreases and water fluctuations in the upstream reduces as well which is very important in irrigation networks. It seems that discharge coefficient can be significantly increased and the efficiency of water usage increases by combining suitable sections and specifying optimum shapes.

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