Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 55(10) (2024) 409-412
DOI: 10.22060/ceej.2023.18920.6999

Investigation Discharge Coefficient and Stage-discharge Equation for Broad-Crested Weirs Including the Effects of Sloping Crest and Upstream and Downstream ramps

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ABSTRACT: Weirs are one of the types of hydraulic structures in water projects that with different cross section have been widely used as flow measuring, controlling and regulating of upstream water surface for turnouts devices, in conveyance water canals or body of dams. In this study, the hydraulic characteristics of flow over broad-crested weirs including the effects of different configurations of sloping crest and upstream and downstream ramps using of finite volume method (FVM) by the ANSYS FLUENT software was investigated. Numerical simulations were validated by experimental results. The results showed that discharge coefficient (Cd) for the BCW-UR-PSC and BCW-UDR-NSC weirs are higher than the BCW-UDR-HC weir. The average increase of the Cd in the BCW-UDR-NSC respect to the BCW-UDR-HC in such a way that $\theta = -4.76° \, \boldsymbol{and} \, -9.46°$ is 18% and 25%, while the average increase of the Cd in the BCW-UDR-PSC respect to the BCW-UDR-HC for same condition ($\theta = +4.76° \, \boldsymbol{and} \, +9.46°$) is 10% and 18%. It was found that both of the BCW-UDR-NSC and BCW-UDR-PSC, the Cd increases with steeper of the crest slope (or increasing). Also, the results showed that for the BCW-UDR-PSC, value of the Cd is $0.35 \le C_d \le .47$, however for the BCW-UDR-NSC, values of the Cd are between $0.42 \le C_d \le 0.48$. This shows that the Cd is affected by the sloping of the crest in such a way that negative slope respect positive slope has more impact in this increase. The average increase of the Cd in the BCW-UDR-NSC respect to the BCW-UDR-PSC is approximately 8%.

Review History:

Received: Aug. 26, 2020
Revised: Jul. 09, 2023
Accepted: Sep. 09, 2023
Available Online: Sep. 17, 2023

Keywords:

Broad–Crested Weir
Discharge Coe-cient
Finite Volume Method
Upstream and Downstream Ramp
Sloping Crest

1- Introduction

Broad-crested weirs are simple flow control structures and are commonly used in open channels, in addition to their use in flow measurements. According to ratio the water head above weir and the length of weir crest (h / L_r), the weirs of finite crest length are categorized into 4 groups [1]. These groups are long-crested weir ($0.0 < h / L_r \le 0.1$), broad-crested weir ($0.1 < h / L_r \le 0.4$), short-crested weirs ($0.4 < h / L_r \le 2$) and sharp–crested weirs ($h / L_r > 2$). The geometry of these type weirs can influence the flow conditions and capacity.

Fritz and Hager [2] conducted a series of experiments on trapezoidal shape weirs with different crest lengths and both the upstream and downstream slopes at1V:2H. They revealed that the discharge coefficient for a broad-crested weir is nearly 10% less than its corresponding value over the embankment-shaped weir

Sargison and Percy [3] investigated the flow of water over embankment weir with changing upstream and downstream ramps slope. Results revealed that decreasing the upstream ramp slope, increases the height of the water surface profile and, hence, the static pressure over the weir crest and also results showed varying the downstream ramp slope has not effect on the discharge coefficient.

Azimi et al. [4] accomplished laboratory investigations on different geometries of broad-crested weirs. The results showed that the discharge coefficient of broad-crested weirs with upstream and downstream ramps is higher than the discharge coefficient of weirs without ramps.

Reviewing the literature indicates that up to now the effect of crest slope on hydraulic properties of broad-crested weirs has not been widely investigated. In this study, in addition to the investigation of flow over the broad-crested weirs with upstream or downstream ramps-or both of them in free flow condition, the hydraulic properties of flow over this type weirs with sloped crest (in two state positive and negative slope), and without sloped crest (horizontal) are numerically investigated. After numerical simulations (*CFD*), hydraulic characteristics of this type weirs such as the water surface profile, discharge coefficient and stage-discharge are considered and then performances of this weirs are compared together.

2- Methodology

2- 1- The governing equations

The stage-discharge equation based the upstream water

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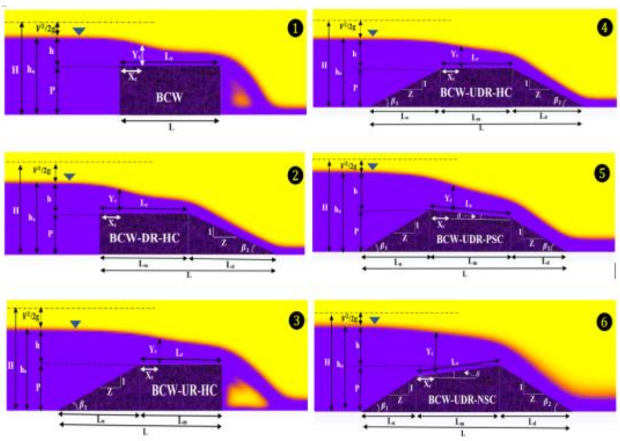

Fig. 1. Definition sketch of broad-crested weirs in this study

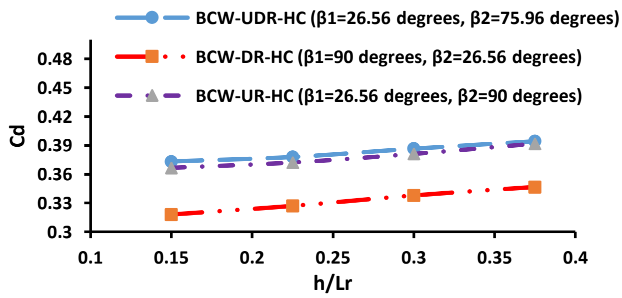

Fig. 2. Comparison of Cd the BCW-UR-HC, BCW-DR-HC, and BCW-UDR-HC

depth over crest for a broad-crested weir can be expressed by the following equation (Eq. (1)):

$$Q = C_d B \sqrt{2gh^3} \quad (1)$$

In which Q is discharge flow (m^2/s), C_d is discharge coefficient (-), B is canal width (m), g is gravitational acceleration (m/s^2), h is water depth over crest in the upstream weir (m).

2- 2- Modeling setup

The schematic definition of investigated broad-crested weirs with different configurations of upstream and/or downstream ramps and slope of crest are shown in Fig.1. In this type of weirs with considering effective factors, the stage-discharge equation can be identified by the following functional equation (Eq. (2)):

$$F_1(Q, h, L_r, B, P, \beta_1, \beta_2, \theta, g, \rho, \mu, \sigma) = 0 \quad (2)$$

Where L_r is the length of weir crest (m), P is height of weir, (m), β_1 and β_2 are upstream and downstream slope angle (degree), respectively; θ is slope of weir crest (degree), σ is fluid surface tension (N/m), ρ is fluid density (kg/m^3), μ is fluid dynamic viscosity (N-s/m^2). Three parameters Q, h and g in functional equation aforementioned were introduced previous section. Based on Buckingham's π theorem, dimensionless parameters can be expressed as shown in Eq. (3). It should be noted, in this functional equation q is discharge flow per unit width (m^2/s).

$$\frac{q}{\sqrt{2g h^{\frac{3}{2}}}} = F_2\left(\frac{\sigma}{\rho g h^2}, \frac{\mu}{\rho h^{\frac{3}{2}} \sqrt{g}}, \frac{h}{L_r}, \frac{h}{P}, \beta_1, \beta_2, \theta\right) \quad (3)$$

Where, the first two non-dimension parameters define Weber number (*We*) and Reynolds number (*Re*) respectively.

$$\frac{q}{\sqrt{2g h^{\frac{3}{2}}}} = F_3\left(\mathrm{Re}, We, \frac{h}{L_r}, \frac{h}{P}, \beta_1, \beta_2, \theta\right) \quad (4)$$

If the effect the first two non-dimension parameters (*We* and *Re*) considered negligible [5], the functional equation in Eq. (4) can be altered in form Eq. (5).

$$C_d = \frac{q}{\sqrt{2g h^{\frac{3}{2}}}} = F_4\left(\frac{h}{L_r}, \frac{h}{P}, \beta_1, \beta_2, \theta\right) \quad (5)$$

2- 3- Numerical Simulation

To simulate the flow over weir a flume with length, height and width of 5.0 m, 0.5 m and 1 m was considered. The crest of weir was placed at a distance of 2.5 m from the entry of flume fixed on all simulations. It should be noted, the weir height (*P*) was constant with value 20 cm.

To investigate the effect of both ramp slope at upstream and downstream and also crest slope in broad-crested weirs, 164 models were constructed using *ANSYS FLUENT* software.

3- Results and Discussion

The comparison of results for the broad-crested weirs such as the *BCW-UR-HC*, *BCW-DR-HC* and *BCW-UDR-HC* are shown in Fig. 2. Based on Figure 2, the Cd for the *BCW-UR-HC*, and *BCW-UDR-HC* are very close together, and the *BCW-UDR-HC* has a slightly higher value for C_d. Therefore, the Cd for the *BCW-UDR-HC* is relatively higher

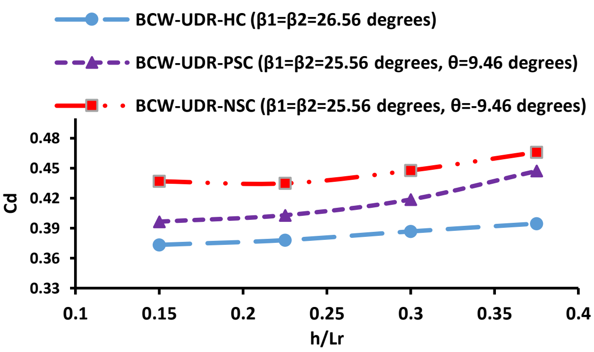

Fig. 3. Comparison of Cd the BCW-UDR-HC, BCW-UDR-PSC and BCW-UDR-NSC

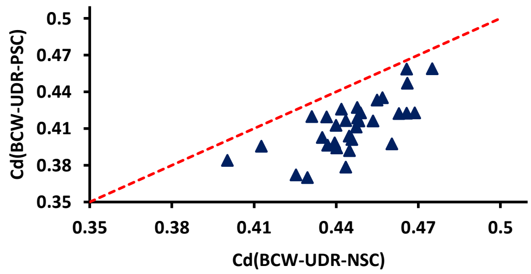

Fig. 4. The scatter plot of Cd for two weirs the BCW-UDR-NSC and BCW-UDR-PSC

than the *BCW-UR-HC* and *BCW-DR-HC*. This shows that the downstream ramp has less effect on the Cd. In fact, unlike the *BCW-UR-HC* and *BCW-UDR-HC*, the *BCW-DR-HC* has lower C_d, because a flow separation zone still exists at the entry of this weir.

In addition, variation of C_d with h/Lr for three the broad crested weirs such as the *BCW-UDR-HC*, *BCW-UDR-PSC* and *BCW-UDR-NSC* are shown in Fig. 3. As shown, the C_d for the *BCW-UR-PSC* and *BCW-UDR-NSC* are higher than the *BCW-UDR-HC*. This shows that the C_d is affected by the sloping of the crest in such a way that negative slope with respect to positive slope has more influence in this increase.

The scatter plot of the C_d for the broad-crested weirs such as the *BCW-UDR-NSC* and *BCW-UDR-PSC* are shown in Fig. 4. As shown, all of data are under the line 45° and this indicate that the C_d of the *BCW-UDR-NSC* is higher than that of the C_d of the *BCW-UDR-PSC*. Reason of this state can be related to the flow convergence caused by the rising crest of weir.

4- Conclusions

In this study, hydraulic characteristics of flow over six type broad-crested weirs with configurations of upstream or/and downstream ramps and with/without of positive and negative crest slope using of finite volume method (*FVM*) by *ANSYS FLUENT* software were investigated. The results are as follows:

The most obvious finding to emerge from this study is that the discharge coefficient (C_d) affected and increased by the sloping of the crest in such a way that negative slope respect positive slope has more influence in this increase.

By applying positive and negative slope for the weir crest the C_d changed in such a way that for BCW-UDR-PSC, value of the C_d is in range $0.35 \le C_d \le 0.47$ and for the BCW-UDR-NSC, value of the C_d is in range $0.42 \le C_d \le 0.48$.

Another important finding was that in both the *BCW-UDR-NSC* and the *BCW-UDR-PSC*, the C_d increases with an increasing slope of crest (or increasing θ).

It was also indicated that the C_d for the BCW-UDR-PSC and the *BCW-UDR-NSC* are higher than the *BCW-UDR-HC*.

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HOW TO CITE THIS ARTICLE

B. Nourani, H. Arvanaghi, F. Salmasi, Investigation Discharge Coefficient and Stage-discharge Equation for Broad-Crested Weirs Including the Effects of Sloping Crest and Upstream and Downstream ramps, Amirkabir J. Civil Eng., 55(10) (2024) 409-412.

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