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Comparative Study of the Discharge Coefficient of Streamlined Weirs

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Abstract

Nowadays, streamlined weirs including circular crested weirs and hydrofoil weirs have been introduced as the weirs with high discharge coefficient (Cd). In this study, the Cd of circular crested weirs including cylindrical, semicircular and quarter-circular weirs were compared with the hydrofoil weirs. This was done using data published in reputable journals. The trend of the published data showed that the o Cd f of the semicircular and cylindrical crested weirs were close to each other and varied between 1.00 and 1.40, while the Cd of the hydrofoil weirs varied between 0.95 and 1.05. It should be noted that for all models the range of the ratio of crest height to weir height varied between 0.5 and 2.10. The results showed that the Cd of the semicircular weir was about 30% higher than that of the hydrofoil weir.

1. Introduction

Weirs are the main structures that have been used in the water engineering projects such as irrigation and drainage networks, dam spillways, and sometimes it is used to control the water surface elevation. The design of weirs is an important part of the water engineering projects especially in the earth dam projects because weakness in their design leads to project failure (Garg, 1987). Weirs were classified into three groups based on the length of their crest as sharp-crested, broad-crested and short-crested weirs (Bos, 1976). Based on the reports, the discharge coefficient of short-crested weirs is more than the others (Azimi Amir et al., 2014; Parsaie and Haghiabi, 2019). Circular crested weirs and hydrofoil weirs are categorized as short crested weirs. So far, different types of circular crested weirs have been proposed, including semicircular, quarter circular and cylindrical weirs. The cylindrical, semicircular, quarter circular and circular crested weirs are generally referred to as circular crested weirs (Afaridegan et al., 2023; Castro-Orgaz, 2010; Ramamurthy Amruthur and Vo, 1993). Circular crested weirs have been welcomed by scientists and widely used in water engineering projects

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due to their ability to pass flows with at least low head losses and their ease of construction(Bagheri and Heidarpour, 2010; Chanson and Montes, 1998; Chen et al., 2022). Chanson and Montes (1998) conducted extensive studies on the hydraulics of the circular crest weir under different conditions. They mentioned that the upstream ramp has an insignificant effect on increasing the performance of the circular crest weir, but the downstream ramp has an obvious effect on increasing the performance of the weir. Schmocker et al. (2011) investigated the effect of the upstream and downstream ramps on the performance of the circular crest weir. They mentioned that the effect of the upstream ramps is marginal, and the downstream ramp has a significant effect on the hydraulic efficiency of the weir. Nowadays, a new type of short crested weir based on the wing of an airplane called hydrofoil weir has been proposed (Bagheri and Kabiri-Samani, 2020; Carollo and Ferro, 2021; Gharehbaghi et al., 2023; Soydan Oksal et al., 2021). The aim of this study is to compare the discharge coefficient of circular crested weirs with that of hydrofoil weirs.

2. Material and methods

As stated in the introduction, the aim of this study is to compare the performance of circular crested weirs with that of hydrofoil weirs. Sketches of all the weirs mentioned are given in Figure 1. In this figure, P is the height of the weir, R is the radius of the crest, H and y are the head and depth of flow above the crest (at sufficient distance from the crest). y_1 and y_2 are the conjugate depths of hydraulic jump. α and β are the angles of the upstream and downstream ramps.

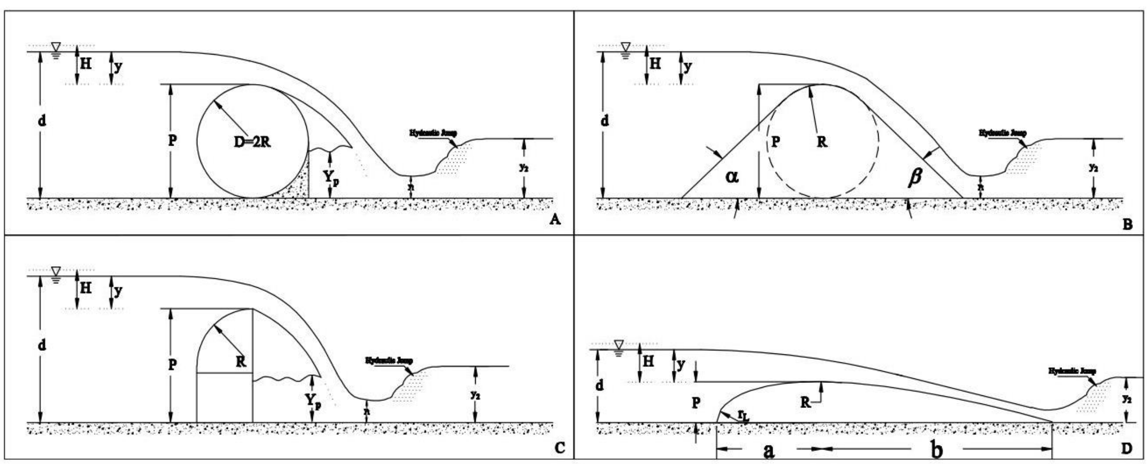

Figure 1. The sketch of circular crested weirs (A: cylindrical, B: semicircular, C: quarter-circular) and D: hydrofoil weir

As mentioned above, circular crested weirs and hydrofoil weirs are categorized as short crested weirs and therefore their discharge capacity can be estimated using Eq. (1) (Soydan Oksal et al., 2021).

$$q = \frac{2}{3} C_d \sqrt{\frac{2}{3} g} H^{1.5} \qquad (1)$$

Where g is the acceleration due to gravity. The parameters affecting the Cd are given in Eq.(2). Using Buckingham's theorem as a dimensional analysis technique, the dimensionless parameters involved in the Cd are derived (Eq. 3.a).

$$C_d = f(P, y, V, R, \alpha, \beta, \rho, \mu, g, \sigma) \qquad (2)$$

$$\overrightarrow{\rho, V, P}: \Pi(y) = \frac{y}{P}$$
$$\left\{H = y + \frac{V^2}{2g} \Rightarrow y \sim H\right\} \Pi(y \sim H) = \frac{H}{P}$$
$$\Pi(R) = \frac{R}{P}$$
$$\Pi(\alpha) = \alpha \quad (3)$$
$$\Pi(\beta) = \beta$$
$$\Pi(\mu) = Re$$
$$\Pi(g) = Fr$$
$$\Pi(\sigma) = We$$
$$\Pi(H) \times \frac{1}{\Pi(R)} = \frac{H}{R}$$

$$C_d = f\left(\frac{H}{R}, \frac{H}{P}, \alpha, \beta, Fr, Re, We\right) \quad (3.a)$$

$$C_d = \begin{cases} \text{semi-circular weir} \Rightarrow f\left(\frac{H}{R}, \frac{H}{P}, \alpha, \beta\right) \\ \text{cylindrical weir} \Rightarrow f\left(\frac{H}{D}\right) \\ \text{quarter-crested weir} \Rightarrow f\left(\frac{H}{R}, \frac{H}{P}, \alpha\right) \\ \text{hydrofoil weir} \Rightarrow f\left(\frac{H}{R}, \frac{H}{P}\right) \end{cases} \quad (3.b)$$

Where μ is the dynamic viscosity, ρ is the flow density and σ is the surface tension. Fr is the Froude number, Re and We are the Reynolds and Weber numbers respectively. As the mentioned weirs are usually constructed perpendicular to the flow path, the approach flow to the weir is subcritical and its Froude number is less than one; thus avoiding the effect of the Froude number on the Cd. It has been attempted to keep the turbulent flow at the weir and the effect of surface tension negligible, so the effect of Reynolds and Weber numbers has not been considered, therefore Eq. (3. a) can be rewritten as Eq. (3. b). The purpose of this study is to compare the Cd of the mentioned weirs with each other, and the effect of parameters such as upstream and downstream gradient on the Cd is not investigated. To compare the performance of the mentioned weirs, the published data related to the hydrofoil weirs by Soydan Oksal et al. (2020) and Bagheri and Heidarpour (2010), and published data related to the quarter-circular crested weirs by Haghiabi et al. (2018); Heidarpour et al. (2008) published data related to the quarter-circular crested weirs by Mohammadzadeh-Habili et al. (2013); Heidarpour et al. (2008); Haghiabi et al. (2018); Heidarpour et al. (2008) and published data related to the cylindrical weirs by Shamsi et al. (2022); Chanson and Montes (1998) were used. For further information, the reader is referred to their original articles. The geometric characteristics of the applied model used, and the associated discharge are given in Table 1.

Table 1. Details of geometric and hydraulic of applied models

Weir Types	a	b	P	R (cm)	r_L	Q (m^3/s)
Hydrofoil Weirs	15	35	4.5	73.53	2.71	0.007 0.016
			5.25	62.77	3.19	
			6	55.25	4.7	
Semicircular Crested Weirs	-	-	15	7,7.5	-	0.0025 0.045
	-	-	21.6		-	
Quarter-Circular Crested Weirs	-	-	10,32.2	8,24	- -	0.004 0.014
Cylindrical Weirs	-	-	0.063 0.025		-	0.002 0.017

3. Results and discussion

This section presents the results of the evaluation and comparison of the models. As mentioned in the Materials and Methods section, the Cd of all models is proportional to the ratio of the crest head to the weir height

(H/P) and the ratio of the crest head to the crest radius (H/P). The H/P shows the effect of the crest curvature on the Cd. The values of Cd versus H/P are shown in Figure 2. As shown in this figure, the Cd of hydrofoil weirs varies between 0.95 and 1.05 considering that the H/P varies between 0.5 and 2.10. For the same H/P range, the Cd of the circular crested weir varies between 1.13 and 1.40. For the same H/P range, the Cd of the quarter circular crested weir varies between 1.00 and 1.25. The Cd of the circular and cylindrical crested weirs are close to each other for the same H/P range, varying between 1.00 and 1.40. The comparison of a quarter-circular weir with a semi-circular weir showed that for values of H/P greater than one (H/P>1.0), the Cd of the semi-circular weir is about 10% higher than that of the quarter-circular weir. The evaluation of the results obtained according to Figure 2 shows that the Cd of the semicircular weir is about 30% higher than that of the hydrofoil weir.

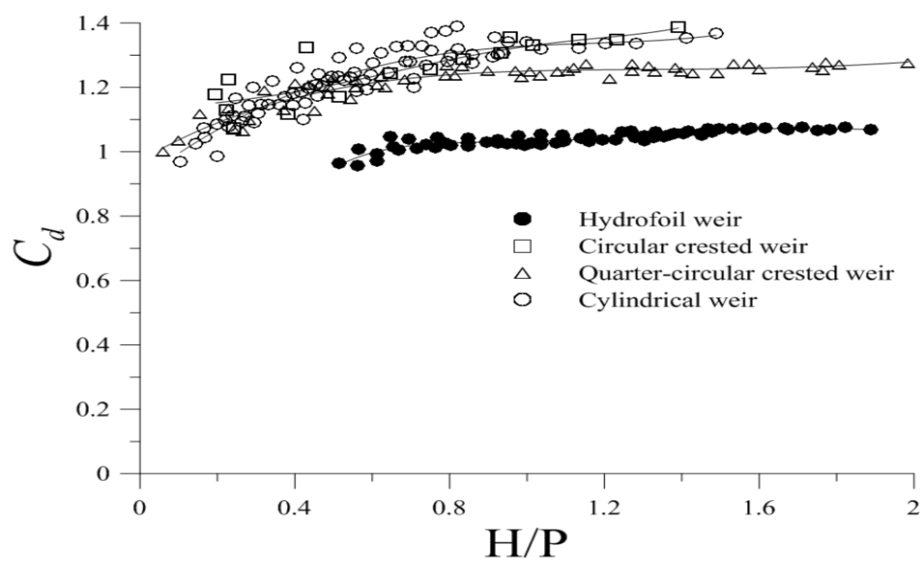

Figure 2. The values of discharge coefficient versus the ratio of flow head over the crest to the weir height

The values of Cd versus H/P are shown in Figure 3. This figure shows the effect of crest curvature on Cd. As shown in this fire and due to the large crest length of the hydrofoil weir, the values of H/P are low. In the range of H/P associated with the hydrofoil weir, the Cd of the hydrofoil weir is close to that of the semicircular crested weir. With increasing head, the effect of the crest curvature decreases for all weirs and for values of H/P greater than one (H/P>1) its effect on Cd is negligible.

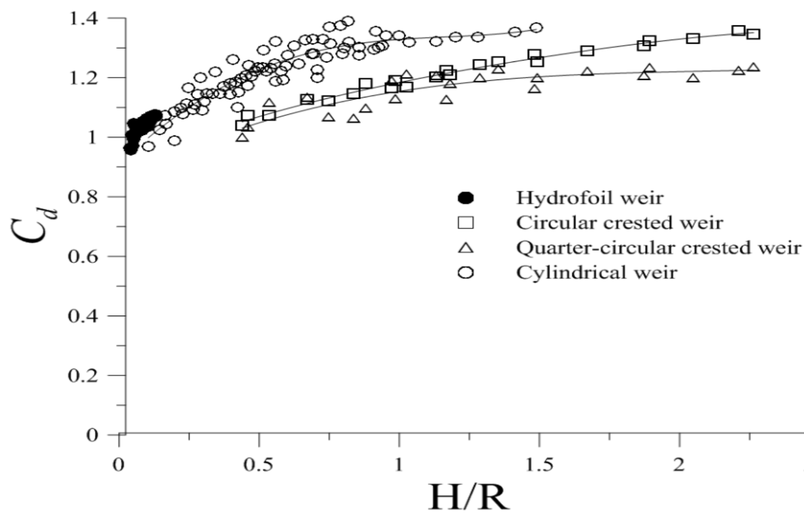

Figure 3. The values of discharge coefficient versus the ratio of flow head over the crest to the radius of crest

4. Conclusion

This study compared the performance of circular crested weirs with that of hydrofoil weirs. The results showed that the performance of the hydrofoil crested weirs was about 30% lower than that of the semicircular crested weirs. The performance of the quarter-circular crested weirs was about 10% lower than that of the semicircular crested weirs. It should be noted that the design of a hydrofoil weir requires more specialist knowledge than a circular crested weir and is much more difficult to construct than a circular crested weir. In addition to being easier to design and construct, the circular crested weir also has a higher discharge coefficient.

Data Availability

The data used to support the findings of this study is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

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