Journal of Ferdowsi Civil Engineering, Vol.32, No.2, 2019.

Experimental Study of Discharge Coefficient of Broad Crest Weir-Circular Culvert Combined Structure

Manouchehr Esmayilvandi[1] Mahdi Asadi-Aghbolaghi[2]

1. Introduction

In second and third degree roads, during heavy flood, the culverts cannot pass the whole flood, and therefore, it is not economical to design a bridge or a high diameter culvert to pass whole water. In such a case, a part of flood water is allowed to pass from the top of the road surface, on the other word, the top of the road acts as a weir, therefore, this hydraulic conveyance structure may be considered as combination of weir-culvert. After flood the water surface would decrease and the road could be used. Culverts have been used to pass water under roads by engineers since long times ago, and many researchers have studied their hydraulics and structures. Although, culverts have simple hydraulic structures seemingly, their design is not simple, and one may not simply categorize their hydraulics in two types, open flow and pressurized flow.

Weirs are categorized by their crest shape and whether they have fully or partially occupied the flow cross section. The weirs are categorized into two main groups: broad crest weirs and sharp crest weirs. Open channel flow measurements are typically done based on measurements of flow depth, which are then correlated with discharge in head-discharge curves. For this purpose the variation of discharge coefficient (C_d) of the combined structure with various affective parameters such as upstream head, culvert inlet shape, length of culvert, culvert internal dimensions, weir crest height, weir side slope angle, and weir width was analyzed.

2. Experimental Program

The experiments were done in the hydraulics laboratory of Shahre-Kord University in Iran. A series of laboratory experiments were conducted on a smooth toughened glass sided and smooth painted bed steel plate flume of 12 m working length. The flume cross sectional area is rectangular shape and has a 40 cm width and 40 cm depth. The measurements of velocity in different points of channel are done by using an Acoustic Doppler Velocitymeter (ADV). Twelve number of models of combined circular culverts and broad crested weirs were set up. These models were divided into 4 groups. These models have different circular culvert diameters (D), different side slopes (tanθ), and the heights (P). The flow rate was measured by a sharp-edge triangular spillway. The discharge can be obtained using $Q = \frac{8}{15}C(\sqrt{2g})(H^{2.5}\tan\frac{\alpha}{2})$, where H is upstream hydraulic head, α is vertex angle, and C is discharge coefficient. Figure 1 shows the schematic diagram of experimental model.

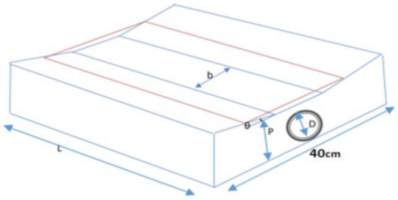

Figure 1. Schematic diagram of experimental model.

Discharge coefficient C_d is obtained for culvert, weir, and combined structure using equations 1, 2, and 3, respectively:

$$Q_c = C_{dc}\frac{\pi D^2}{4}\sqrt{2g(Y-y_1)} \quad (1)$$

$$Q_W = C_{dw}\left(\frac{2}{3}\sqrt{2g}\,bH^{\frac{3}{2}} + \frac{8}{15}\sqrt{2g}\tan\theta\, H^{\frac{5}{2}}\right) \quad (2)$$

$$Q = C_d\left(\sqrt{2g(Y-y_1)}\frac{\pi D^2}{4} + \frac{2}{3}\sqrt{2g}\,bH^{\frac{3}{2}} + \frac{8}{15}\sqrt{2g}\tan\theta\, H^{\frac{5}{2}}\right. \quad (3)$$

where g is the gravitational acceleration, Q_C, Q_W, and Q are the discharge of culvert, weir, and combined structure, respectively, C_{dc}, C_{dw}, and C_d are the discharge coefficient of the culvert, weir and combined structure, respectively, D is the culvert diameter, Y is the upstream total head above the bottom of the culvert, y_1 is the flow depth downstream of the structure, b is the bottom width of weir, H is the upstream head above the bottom of weir, and θ is the side angle of weir. A dimensional analysis is made to find important dimensionless parameters affecting the discharge coefficient. Stage discharge rating curve for models 1 and 2 are shown in Figure 2. As depicted in the figure, at a constant head, the discharge of combine structure is greater than the summation of discharge of culvert and weir flow structure.

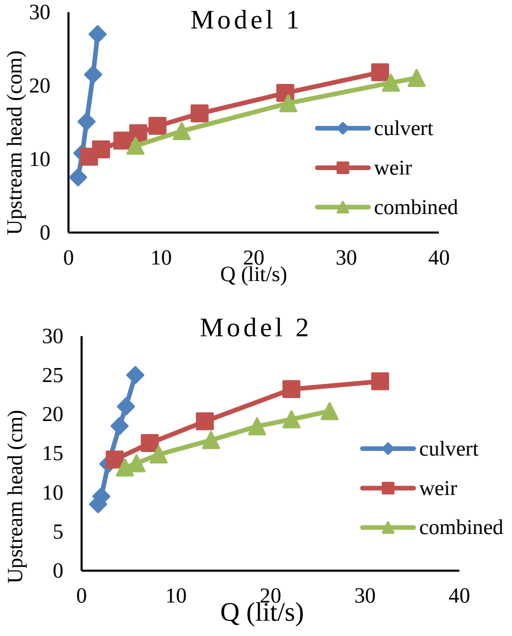

Figure 2. Stage discharge rating curve for models 1and 2

---

[1] MSc of Hydraulic structure, water engineering department, Faculty of agriculture, Shahrekord University, Shahrekord, Iran.

[2] Corresponding Author, Assistant Professor, Water engineering department, Faculty of agriculture, Shahrekord University, Shahrekord, Iran. Emali: mahdi.asadi.a@gmail.com

The discharge coefficient for combined structure (C_d) was plotted against the dimensionless parameters, such as H/L, H/b, H/D, and H/p; the results are shown in figures 3, for models 1 and 2. The results showed that the discharge coefficient increases with increase of these dimensionless parameters for all models. Furthermore, among them H/L, and H/b has more effect on discharge coefficient. The discharge coefficient for models 1 to 3, 4 to 6, 7 to 9, and 10 to 12, is between, 0.27 to 0.59, 0.48 to 0.75, 0.4 to 0.74, and 0.4 to 0.74, respectively. These figures depict that the discharge coefficient is between 0.27 to 0.75, which the minimum value is for model 6 and the minimum value belongs to second model. The discharge coefficient increase with decrease of weir height.

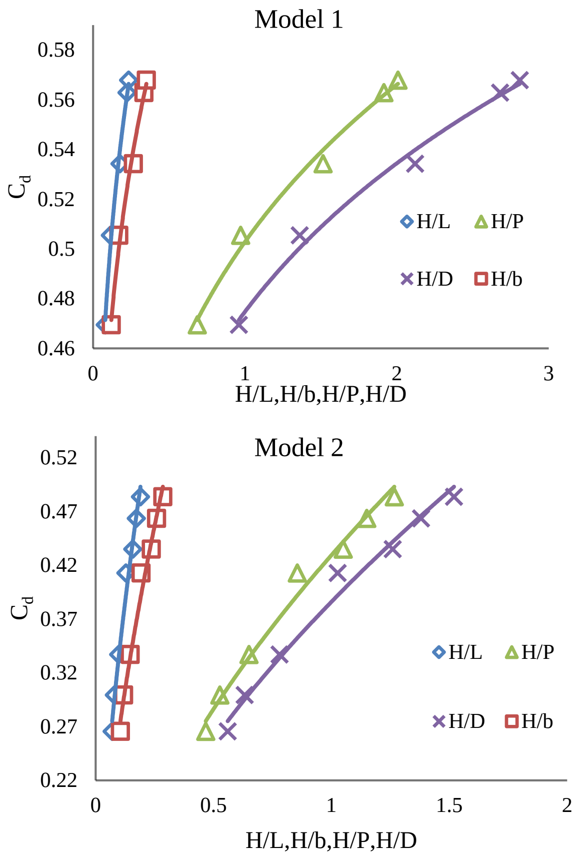

Figure 3. Discharge coefficient versus dimensionless parameters for models 1 and 2

The results were compared with Bodhaine's (1976) and Guven et al.'s (2013) studies. The discharge coefficient of culvert versus Y/D for present study, Bodhain's study for circular culvert and Guven et al.'s study for box culvert is depicted in Fig. 4. In all models, discharge coefficient increase with increase of Y/D. As seen in the figure, there is good agreement between present study and previous works. It is worth noting that Guven et al.'s study was done on a combined box culvert-weir.

An equation was developed for discharge coefficient as a function of the dimensionless terms for the culvert, the weir and the combined structure. The results showed that C_d increases as H/P (the ratio of the total head of water above the weir crest to the height of the weir crest) increases. An equation is obtained for discharge coefficient of circular culvert, using linear regression, with R^2=0.89:

$$C_d = 0.27 + 0.11\frac{y}{D} - 0.049\frac{y}{L} + 0.51Fr \tag{4}$$

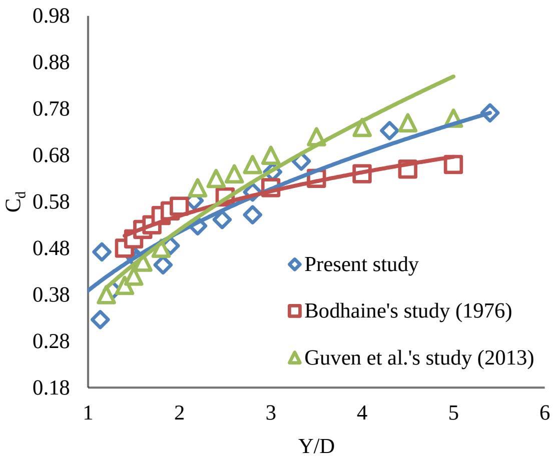

Figure 4. Discharge coefficient versus Y/D for present study, Bodhaine's study, and Guven et al.' study

where, RMSE (root mean square error) is 0.0395 and MRE (mean relative error) is 0.061, and for the weir, with R^2=0.88:

$$C_d = 0.82 + 0.14Fr + 0.51\frac{H}{P} - 0.71\frac{b}{L} - 0.75\tan\theta \tag{5}$$

where, RMSE is 0.0366 and MRE is 0.058, and for the combined structure, with R^2=0.71:

$$C_d = 0.42 - 0.25Fr + 0.018\frac{P}{D} + 0.21\frac{H}{b} + 0.27\tan\theta + 0.13\frac{H}{L}. \tag{6}$$

where, RMSE is 0.0592 and MRE is 0.088. The results were compared to previous study.

3. Conclusion

In this investigation, discharge coefficient is studied for a combined culvert-weir system. The results showed that discharge coefficient is varying between 0.25 and 0.73, for the combined structure, between 0.25 and 0.63 for the weir, and between 0.33 and 0.77 for the culvert. The dimensionless parameter H/D (head to diameter) has the biggest effect on discharge coefficient. Furthermore, with decreasing lateral slope of the weir, the discharge coefficient increases in both weir and combined structure. In a constant head, discharge of combined structure is greater than the summation of discharge of the weir and culvert. The reason is that when each of structures works separately, the contraction of streamlines becomes greater than those of combined structure and therefore, energy loss increases, so, the discharge of combined structure is greater than summation of both structures, separately. In addition, the regression equations are presented for estimation of discharge coefficient.