Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 55(11) (2024) 489-492
DOI: 10.22060/ceej.2023.22166.7918

Calibration of unsteady flow in Crump Weir

S. M. h. Badiei[1], A. Khoshfetrat[1], M. Saadat [2]

[1] Department of Civil Engineering, Isfahan (Khorasgan) Branch, Islamic Azad University, Isfahan, Iran.
[2] Department of Civil Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran.

ABSTRACT: Crump weir is widely used to measure flow rate in open channels. In this study, flow rate calibration is experimentally investigated for an unsteady free flow. To consider the effect of flow rate on flow coefficient, increasing and decreasing flow rate regimes were considered. Experimental tests were performed in a laboratory flume equipped with real-time data acquisition and recording system. The behavior of the flow rate coefficient was investigated as a function of three dimensionless parameters containing weir height to the upstream water height ratio, the weir length to upstream water height ratio, and the weir width to upstream water height ratio. Results show that the flow rate coefficient is in reverse correspondence with all dimensionless parameters so that with an increase in each of these parameters, the flow rate coefficient decreases. Finally using genetic algorithm, the optimization of the flow rate coefficient was performed. It was shown that the calibrated flow rate coefficient lies between 0.4 and 0.7.

Review History:

Received: Feb. 05, 2023
Revised: Oct. 15, 2023
Accepted: Oct. 22, 2023
Available Online: Nov. 08, 2023

Keywords:

Unsteady flow
crump weir
flow rate coefficient
genetic algorithm
calibration

1- Introduction

Weirs are among the oldest hydraulic structures used on rivers in Iran, India, Egypt, and China to increase the water level and divert river flow in the desired direction [1]. Bazin was the first who conduct experiments on the rectangular weir [2]. By conducting experiments on a wide rectangular weir, Horton then showed that the flow rate coefficient is only a function of the H/L ratio, where H is the total water load on the weir and L is the length of the weir [3]. In recent studies, new methods such as numerical simulations, statistical methods, and the use of artificial intelligence were pursued [4-6]. With flow complexity in unsteady conditions, few studies have been done so far. Bortoni for instance assumed that the flow rate coefficient in the unsteady flow regime is constant and then by deriving the general relationship of the flow in weirs, calibrated rectangular and triangular sharp-edged weirs. They also presented a relationship for the flow rate coefficient in the unsteady flow state by deriving it from the water head. They dealt with time differential dh/dt and considered this method applicable for other overflows [7]. In a laboratory study, Arafi et al. addressed the calibration of the weir flow coefficient of a piano key in an unsteady state. Then, based on these conditions and using the analytical method, the flow rate coefficient in the weir of the piano key has been determined [8].

2- Methodology

Here, the dimensional analysis of the Crump Weir is investigated using the Buckingham pi theorem for a free unsteady flow condition. Figure 1 shows the schematic view of the flow in Crump Weir. The parameters affecting the hydraulic flow of Crump Weir are categorized as 1. Geometric characteristics include the height of the weir (P), the length of the weir floor in the flow direction (L_w), and the upstream and downstream angles of the weir (α) and (β) respectively, 2. Flow-related characteristics including flow rate per unit width (q), depth of water on the weir in the upstream part of the flow (h), flow depth upstream of the weir (y_0), flow depth downstream of the weir (y_1) and gravity acceleration (g) and finally 3. Fluid properties include specific mass (ρ), dynamic viscosity (μ), and surface tension of liquid (σ). The objective function is the flow coefficient C_d in free flow condition which should be calibrated here. Using the normalized parameters and simplifying assumptions, C_d can be defined according to equation 1.

$$C_d = G\left(\frac{b}{h}, \frac{L_w}{h}, \frac{P}{h}\right) \quad (1)$$

*Corresponding author's email: khoshfetrat@khuisf.ac.ir

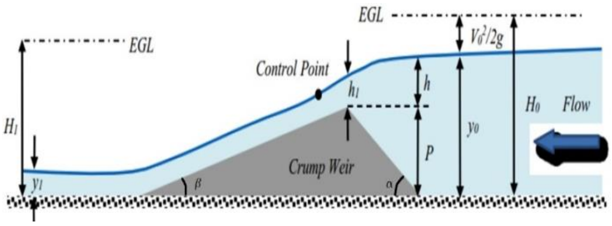


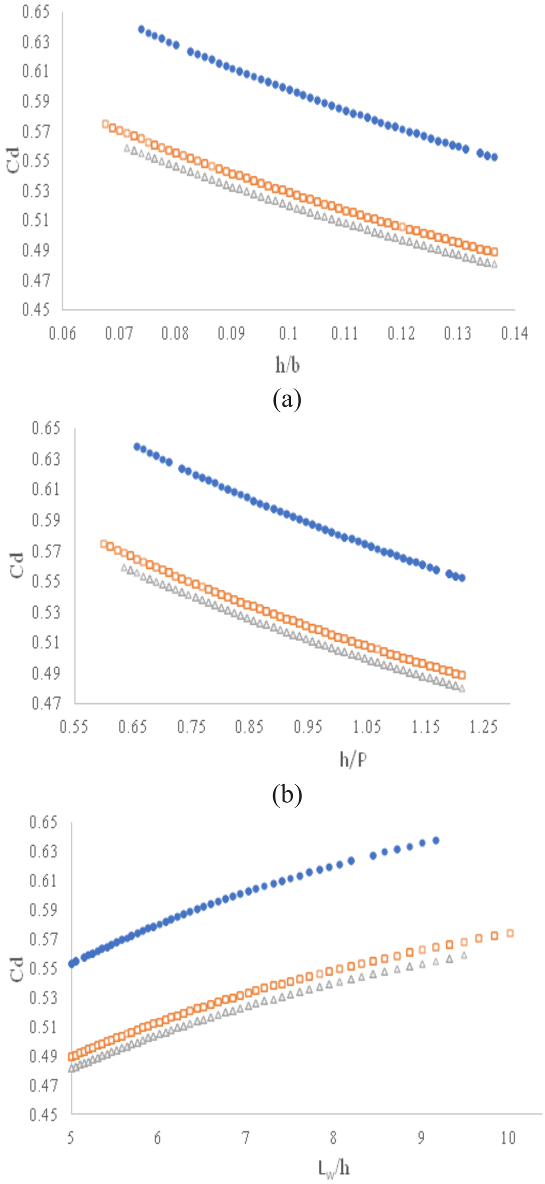
Fig. 1- Schematic illustration of Crump weir

Therefore, with an experimental investigation by a Hydraulic lab's flume of Islamic Azad University of Isfahan (Khorasgan), the exact values of three influencing parameters namely P/h, L_w/h, and b/h is measured and computed for flow coefficient calibration. The Crump weir studied here has height (P), length (L_w), and width (b) of 9, 54, and 80 cm respectively. Therefore, the only needed parameter for calibration is the depth of water on the weir in the upstream part of the flow (h) which can be measured in the flume experimentation. Here, different flows with increasing and decreasing rates are running over the weir and the depth h is precisely measured in real-time at the predefined distance from the weir. The next step is to explicitly define the mathematical formulation of the objective function. Then, the optimization of the objective function will take place using Genetic Algorithm in MATLAB software package. To find the mathematical relation, the flow formulation of Crump weir can be used as presented in equation 2.

$$q=\frac{2}{3}C_d\sqrt{2g}\,by_0^{\frac{3}{2}} \tag{2}$$

For unsteady condition, the differential of equation 2 should be considered. if C_d is separated, then equation 2 in its differential form can be rewritten as equation (3). In equation 3, it was assumed that the C_d is a constant value with time.

$$C_d=\frac{\frac{dQ}{dt}}{b\sqrt{2gy_0}\,\frac{dh}{dt}} \tag{3}$$



(a)

(b)

(c)

Fig. 2. the effect of different parameters on Cd at different increasing flow rates (a) the effect of h/b, (b) the effect of h/p, and (c) the effect of L_w/h

3- Results and Discussion

Extended The effect of the dimensionless parameters on $C_{d,}$ was calculated and results for the experiments with increasing flow rate are presented in Figure 2. In this figure, blue, red, and gray lines correspond to conditions where the flow rate increases with 0.2, 0.1, and 0.66 lit/s rates respectively. As it is clear from Figure 2, with the reduction of the ratio of the height of the water on the weir to the width of the weir (h/b) and the ratio of the height of the water on the weir to the height of the weir (h/P), the value of the C_d increases, but with the reduction of the ratio of the weir floor According to the height of the water on the weir (L_w/h), C_d decreased. Also, with the decrease of the flow rate gradient, the value of the flow rate coefficient at the same h/b, h/P, and L_w/h ratios has always decreased. it is, however, expected that reducing the flow rate gradient from 0.066 lit/s will not have any effect on the changes in the flow rate coefficient.

Similar diagrams with decreasing flow rate gradients were obtained, but in this case, C_d values were higher than their corresponding increasing gradients. Finally using the genetic algorithm, the calibrated value of C_d, was computed and presented in Table 1.

Table 1. Calibrated flow rate coefficient Cd in increasing and decreasing flow rate gradients

flow rate gradient	increasing flow rate gradient	Decreasing flow rate gradient
0.2 lit /s	0.5179	0.5839
0.1 lit/s	0.4796	0.5501
0.066 lit/s	0.4757	0.5099

4- Conclusions

The following highlights are the most important findings of this study.

C_d decreases with the decrease in b/h, P/h, and L_w/h.

The calibrated C_d under different unsteady free flow patterns varies between 0.4 and 0.7.

C_d in the increasing flow rate gradient regime is smaller than that in the decreasing gradient regime.

C_d changes more in transition between two gradients of 0.2 and 0.1 lit/s than that of 0.1 and 0.066 lit/s.

From gradient of 0.066 lit /s, it seems more decrease in gradient would not make much effect on C_d.

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HOW TO CITE THIS ARTICLE
S. M. h. Badiei, A. Khoshfetrat, M. Saadat, Calibration of unsteady flow in Crump Weir, Amirkabir J. Civil Eng., 55(11) (2024) 489-492.

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