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ESTIMATION OF DISHARGE COEFFICIENT ON WEIR CONFIGURATION BASED ON FLOW RATE AND VELOCITY

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ABSTRACT

The development of water treatment and water resources considers the flow rate adjusted using a weir. Weir is designed with many hydraulic factors, including the coefficient of discharge (C_d). Characteristics of the value of C_d show a decreasing trend on triangular and rectangular weirs. The value of C_d varies based on the flow's characteristics and the channel's geometry. Estimation of the best C_d value in flow discharge engineering and sediment deposition is necessary to know the accuracy of weir geometry. Some plans in water treatment and water resource building sometimes assume a C_d value based on literature. This study aims to estimate the value of C_d based on variations in flow rate and was conducted on a laboratory scale with weir shape limitations in the form of triangles and rectangles. The water sample was discharged by a water pump into an open channel. The angle of the weir opening was determined for the rectangular and triangular weir of 90°. Flow monitoring included flow discharge through the use of a current meter. Water was recycled in each measurement with a total of 60 cycles. The C_d values in a triangular weir were greater than in a rectangular weir. The C_d values for the rectangular weir ranged from 0.068 to 0.089, while the C_d values for the triangular weir ranged from 0.557 to 0.598. This value indicated that the greater the flow rate, the lower the C_d value. Therefore, weir configuration of water discharged using a triangular weir was better than a rectangular weir at low flow rates, less than 0.05 m^3/s.

Keywords: Discharge coefficient; Flow rate; Velocity; Water; Weir

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1. INTRODUCTION

Planning for water treatment and water resources development significantly considers the flow rate. In general, the flow rate adjustment method is carried out using a weir. Weir construction reduces upstream velocity, precipitating sediment and reducing flow capacity (Husam et al., 2020). In addition, the weir is operated as a flow divider, energy neutralizer, and hydraulic structures protector from possible damage (Niazkar & Afzali, 2018). The weir consists of vertical thin walls, restricting flow, placed normal to the channel sidewalls (Ferro & Aydin, 2019; Li et al., 2021). Weir is considered a unique form of a large orifice with a free water surface in an open channel (Lonescu et al., 2019). In the practice and design of water treatment, a side compound of weir is designed to separate the flow rate from the main channel to the branch channel (Ansari et al., 2019; Li et al., 2021). The stream overflows to a certain height above the weir opening and flows through the top of the weir. The flow height is used as a flow rate parameter. Therefore, accurate measurement of flow rate through the weir is considerable practical importance using several hydraulic aspects.

Standard geometric weir openings can be rectangular, triangular, trapezoidal, parabolic, semicircular, semi-cylindrical, arched, and proportional and have been widely studied in various literature (Sangsefidi, Y., Mehraein, M., & Ghodsian, 2015; Namaee & Shadpoorian, 2016). Weirs with triangular or rectangular openings are the ones most commonly applied to a wide variety of flow hydraulic systems. A triangular weir in the form of a thin plate with a V-shaped opening (v-notch) is one of the oldest, most uncomplicated, and most precise flow-measuring devices in both natural and artificial flow systems (Murthy, K. K, 1995). The rectangular weir can be found in open channels in wastewater distribution and treatment systems. Weirs with v-notch openings are typically used to measure low flow rates for low operating ranges. In contrast, rectangular weirs are more suitable for setting relatively high flow rates for a more comprehensive operating range (Irzooki et al., 2014).

Weir was designed considering many hydraulic factors and one of which is the coefficient of discharge (C_d). The C_d value is defined as the ratio of the actual flow rate to the theoretical flow rate. In other terms, the C_d is defined as the function of the flow head over the top of the weir to the weir height (Akhbari et al., 2017). C_d values vary based on flow characteristics and channel geometry. C_d is a complex parameter and depends on such quantities as friction, surface tension, pressure distribution, lateral contraction, vertical drag, velocity profile, and the geometric shape of the weir. Some research results reveal that the C_d value is related to the Froude number in the upstream weir, the ratio of weir height to flow depth, the ratio of length to width of the central canal, and the length of the broad-crested weir to the width of the central canal (Parsaie & Haghiabi, 2015). Therefore, the best estimation of C_d values in flow discharge engineering and sediment deposition is needed to determine the accuracy of the weir geometry. Some plans in water treatment and water resources buildings sometimes only assume C_d values based on the literature. However, the value of C_d can vary according to the dynamic conditions of the flowrate. Consequently, the main objective of this study was to estimate the value of C_d based on flowrate and velocity variations in flow rate. This research was conducted on a laboratory scale with weir shape limitations in the form of triangles and rectangles.

2. METHODS

The research sample was taken from wells at the Hydraulics and Hydromechanics Laboratory, Department of Civil and Environmental Engineering, IPB University. The water sample was discharged by a water pump into an open channel. This study aims to observe the flow characteristics of triangular and rectangular weirs (Figure 1). Flow monitoring included flow discharge through the use of a current meter. Variables related to the calculation of flow discharge were current meter frequency (N), flow velocity (v), gravitational acceleration (g), weir width (b), and water flow surface height (h). The discharge measurement was carried out repeatedly until ten discharge variations were obtained for each weir geometry shape. The height of the sluice (H) and the overflow are measured at each discharge variation. The weir opening angle was determined for a triangular weir to be 90°.

The frequency of the current meter or the number of rounds that occur every second is the relationship between the number of rounds and the travel time (t). The number of rounds in each measurement is 60 rounds. The value of N can be obtained using Equation (1).

$$N = \frac{60}{t} \tag{1}$$

Where N is frequency of the current meter (rps) and t in seconds.

Estimating flow velocity is the relationship of the frequency of the current meter with other calibrated quantities. Therefore, flow velocity can be determined using Equation (2).

$$v = 0{,}13N - 0{,}01 \tag{2}$$

Where v is velocity (m/s).

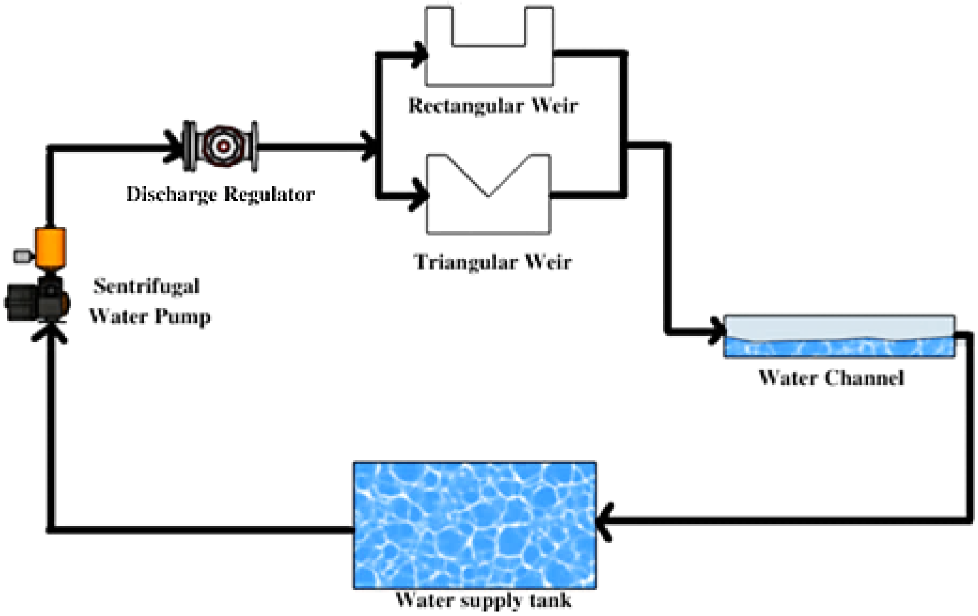

Figure 1. Experimental scheme in determining the discharge coefficient (C_d) value

The flow surface height in an open channel was measured to find the cross-sectional area of the flow determined using the product of the flow surface height (h) with the channel width (b). The product of the cross-sectional area of the flow and the flow velocity gives the flow rate, Q (Equation (3)).

$$Q = A \cdot v \tag{3}$$

Where Q is flow rate (m^3/s) and A is cross-sectional area of flow (m^2)

Furthermore, the flow rate determines C_d based on rectangular and triangular weir shapes. The relationship between the flow rate of the rectangular weir and other hydraulic parameters is shown by Equation (4).

$$Q = \frac{2}{3} C_d \sqrt{2g} b \left[\left(H + \frac{\alpha v^2}{2g} \right)^{\frac{3}{2}} + \left(\frac{\alpha v^2}{2g} \right)^{\frac{3}{2}} \right] \tag{4}$$

Where C_d is coefficient of discharge, g is acceleration due to gravity (m^2/s), weir distance from the surface (m), b is weir width (m), α is Coriolis coefficient, and $v^2/2g$ = head speed (m).

In addition, the relationship between the flow rate of the triangular weir with other hydraulic parameters is shown by Eq. (5) (Li et al., 2021).

$$Q = \frac{8}{15} C_d \sqrt{2g} \tan\frac{\theta}{2} \left[\left(\mathrm{H} + \frac{\alpha v^2}{2g} \right)^{\frac{3}{2}} - \left(\frac{\alpha v^2}{2g} \right)^{\frac{3}{2}} \right] \tag{5}$$

The value of the energy correction factor or Coriolis coefficient (α) can be calculated through Eq. (6), where v_m is maximum velocity during test (m/s).

$$\alpha = \frac{v^3 \Delta A}{v_m{}^3 A} \quad (6)$$

3. RESULTS AND DISCUSSION

The effect of the drawdown and the geometry model causes the flow rate value to be lower than the rated discharge. The measured discharge needs to be corrected with the C_d coefficient (H. H. Alwan & Al-Mohammed, 2018). Theoretical measurement of discharge generally ignores differences in pressure and flow velocity (Komarudin et al., 2019). The discharge data in this study was obtained through the velocity method approach by measuring current velocity. The current meter resulted fairly good accuracy value because it was compatible on the principle of the flow velocity and the rotational speed relationship of the current meter propeller according to the equation v = *a*n + *b*. The value of *a* and *b* are constants determined by calibration of the instrument in the laboratory.

The velocity value obtained is then used in determining the C_d value mathematically using equations (4) and (5). Coriolis coefficient (α) is calculated using equation (6) based on the results of speed measurements during the data collection process, and *b* is the channel width. The values of velocity, flow rate, head, and flow coefficient obtained in this study for rectangular weirs and triangular weirs are attached in Table 1. Water discharged in channel with triangular weirs had a greater velocity than water discharged in channel with rectangular weirs. C_d values in the rectangular weir ranged from 0.068 - 0.089. Meanwhile, the value of C_d on the triangular weir ranged from 0.557 - 0.598.

Table 1. Flow characteristics based on weir geometric shapes

Geometric shape	*v* (m/s)	*Q* (m^3/s)	*H* (m)	C_d
Rectangular weir	0,7548	0,0420	0,1030	0,0087
	0,7578	0,0421	0,1010	0,0089
	0,7974	0,0431	0,0940	0,0089
	0,8441	0,0496	0,1080	0,0077
	0,8804	0,0504	0,1090	0,0069
	0,8686	0,0504	0,1090	0,0072
	0,8676	0,0507	0,1100	0,0072
	0,8914	0,0513	0,1090	0,0068
	0,8657	0,0516	0,1100	0,0074
	0,8814	0,0518	0,1090	0,0071
Triangular weir	1,2178	0,0414	0,1800	0,0074
	1,1808	0,0425	0,1820	0,0087
	1,2530	0,0436	0,1730	0,0068
	1,2121	0,0436	0,1810	0,0072
	1,2273	0,0452	0,1820	0,0089
	1,2550	0,0467	0,1810	0,0089
	1,2530	0,0476	0,1850	0,0069
	1,2673	0,0482	0,1840	0,0077
	1,3301	0,0493	0,1810	0,0072
	1,3392	0,0498	0,1810	0,0071

Simple linear regression was used to see the C_d pattern on rectangular and triangular weirs for several discharge variations. The coefficient of determination (R^2) for linear regression on a rectangular weir curve was 0.92 (Figure 2), while in the triangular weir curve was 0.93 (Figure 3). According to many statisticians, a coefficient of determination value of more than 70% indicates that the data can be accepted very well (Husam H. Alwan et al., 2020).

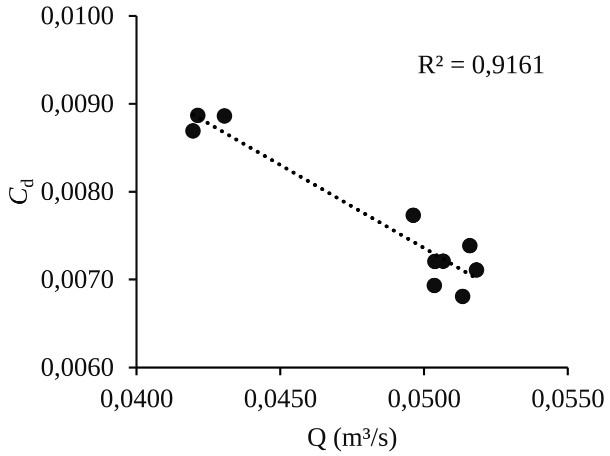

Figure 2. The Relationship Between Flow Rate and C_d in A Rectangular Weir

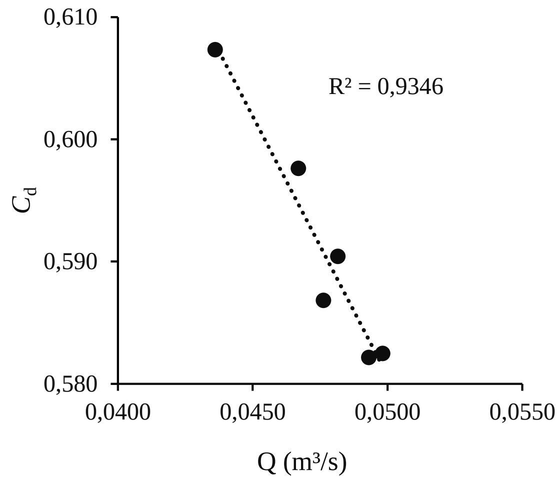

Figure 3. The Relationship between Flow Rate and C_d in A Triangular Weir

The rectangular weir curve and the triangular weir curve show a downward trend. The value of C_d on the rectangular weir and triangular weir decreases when the flow rate increases. According to SNI 8137:2015 concerning the Measurement of Discharge in Open Channels Using Measuring Buildings of the Upper Spill Type, the C_d value for a rectangular weir is 0.73; while the C_d value for triangular weir triangles is 0.3 (Badan Standardisasi Nasional, 2015). Field conditions cause C_d value fluctuations in various works of literature. The minimum height requirement is set at 5 cm for triangular weirs and 2 cm for rectangular weirs. Such conditions are not met for small discharges measured in the laboratory (Ionescu et al., 2019). The triangular weir has a more considerable C_d value for flow rates below 0.05 m^3/s. These results indicate that the triangular weir has greater sensitivity than the rectangular weir. A triangular weir is better than a rectangular weir at low flow rates of less than 0.05 m^3/s. Rectangular weirs produce more accurate discharge only if they meet field conditions, namely a minimum height of 2 cm (Ionescu et al., 2019). In real construction, the resulting C_d values are an accumulation of variables that are not estimated the derivation of flow rate from the depth of weir, such as surface tension, viscosity, velocity distribution in the approach channel, and current curvature due to weir contraction. Thus, the C_d value should not be kept constant, but adjusted to the discharge conditions as shown in Table 1.

Much literature states that the C_d is the product of the contraction coefficient (C_c) and velocity coefficient (C_v) (Dabral et al., 2014). C_c is the ratio of the area of the air passage screen to the area of the weir, while C_v is the ratio of the actual speed to the measured speed. Based on research that was conducted by Hicks & Slaton (2014), the C_d value is effectively directly proportional only to the contraction coefficient. It is related to the velocity coefficient depending on flow type and measurement location due to differences in flow velocity at each point. The discharge coefficient of C_d associated with the overflow energy heads varies with the relative upstream slope. Decreasing the upstream face slope makes the water surface profile fall into smooth curvature and become flatter. Moreover, the C_d coefficient tends to increase with decreasing upstream weir slope. The C_d value is a non-dimensional number that cannot be calculated precisely for construction calculations. Therefore, in the implementation in the field, the value of C_d varies greatly. The C_d value for the rectangular weir is in the range of 0.5-0.6 with a decreasing trend (Ionescu et al., 2019); 0.4-0.85 (Febrianto, 2018); 0.66-0.76 (Hicks & Slaton, 2014), and many more. Meanwhile, the C_d value for the triangular weir is in the range of 0.6-0.8 with a logarithmic trend (Ionescu et al., 2019). Azamathulla et al., (2016) stated that there are at least ten well-known empirical formulas for calculating the side weir C_d coefficient. However, the trend given has implications for the best accuracy in determining the amount of flow discharge whose usefulness depends on the purpose of building a particular construction.

4. CONCLUSION

Based on the research, in a triangular weir, water flows at a more incredible speed than in a rectangular weir. Characteristics of the value of C_d show a decreasing trend on triangular and rectangular weirs. The C_d values for the rectangular weir ranged from 0.068 to 0.089, while the C_d values for the triangular weir ranged from 0.557 to 0.598. This value indicates that the greater the flow rate, the lower the C_d value. A triangular weir is better than a rectangular weir at low flow rates, less than 0.05 m^3/s, because a triangular weir has a higher sensitivity in determining flow rate. A rectangular weir only produces a more accurate discharge if it meets field conditions, namely a minimum height of 2 cm. The C_d trend given has implications for the best accuracy in determining the amount of flow discharge whose usefulness depends on the purpose of building a particular construction.

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