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FOREWORD

Welcome to the 10th volume and 1st issue of the ESTEEM Academic Journal (EAJ), an online peer-refereed academic journal of engineering, science and technology.Since the beginning of this year, a number of articles have been sent to us; some of which still being under review in their first or second phase, and the first eight of them are being published now, others following in the subsequent issue. Article submissions came from different UiTM branch campuses across the country and the manuscripts covered a wide range of engineering, science and technology topics, all of them being interesting and innovative.

First and foremost, we would like to extend our sincere appreciation and utmost gratitude to Associate Professor Dr. Ngah Ramzi Hamzah, Rector of UiTM (Pulau Pinang), Dr. Mohd Mahadzir Mohammud@Mahmood, Deputy Rector of Academic Affairs and Dr. Mohd Subri Tahir, Deputy Rector of Research, Industry, Community & Alumni Network for their generous support towards the successful publication of this issue. Not to be forgotten also are the constructive and invaluable comments given by the eminent panels of external reviewers and language editors who have worked assiduously towards ensuring that all the articles published in this issue are of the highest quality. In addition, we would like to thank the authors who have submitted articles to EAJ, trusting Editor and Editorial Board and thus endorsing a new initiative and an innovative academic organ and, in doing so, encouraging many more authors to submit their manuscripts as well, knowing that they and their work will be in good hands and that their findings will be published on a short-term basis. Last but not least, a special acknowledgement is dedicated to those members of the Editorial Board who have contributed to the making of this issue and whose work has increased the quality of articles even more. Although there will always be cases in which manuscripts will be rejected, our work so far has shown that the board members' motivation has been, and will be, to make publications possible rather than to block them. By means of intensive communication with authors, academic quality is and will be guaranteed and promising research findings are and will be conveyed to the academia in a functional manner.

Dr. Chang Siu Hua
Chief Editor
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ESTEEM Academic Journal
Vol. 10, No. 1, June 2014

CONTENTS OF JOURNAL

p-ISSN 1675-7939; e-ISSN 2289-4934

ESTEEM Academic Journal
Vol. 10, No. 1, June 2014, 31-39

DISCHARGE EQUATION OF CONTRACTED RECTANGULAR FALAT-CRESTED SLIT WEIRS

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ABSTRACT

This paper presents a study on water flow over a rectangular flat-crested slit weir where the discharge equation is obtained in terms of the dimensionless variable of H/P and H/t. This study was carried out on nine different weir heights with the weir width and weir crest thickness at 10 mm and 4 mm, respectively. The discharge coefficient is determined experimentally using the small discharges by varying weir heights. Regression analysis is conducted to establish the relationship of the discharge coefficient with both the H/P and the H/t taken as the variables. The linear relationship forms are obtained, which provide an easy means of estimating the discharge coefficient.

Keywords: discharge equation; discharge coefficient; slit weir; water discharge.

1. INTRODUCTION

A weir is a structure built across a channel to raise the level of water; with the water flowing over it, the discharge can thus be measured. Weirs are designed for flow measurement or as a flow regulation structure to estimate the amount of discharge. Therefore, knowing an accurate discharge coefficient is important for its substitution into a discharge equation. Discharge equation for a weir is developed empirically using an extensive experimental data because it cannot be derived exactly due to the flow pattern of one weir differs from another of a different shape and the flow pattern raise with the discharge (French, 1995). A number of empirical equations have been developed by previous researchers to enable discharge coefficient estimates to be made. The researchers performed weir experiments to obtain the discharge coefficient at different parameter such as weir heights, weir widths, weir heads, and flow rates. Johnson (2000), who studied the discharge coefficient of rectangular flat-topped and sharp-crested weirs, found that the discharge coefficient is a function of H_t/t and H/P, respectively.

Ackers, White, Perkins, and Harrison (1978) stated that Kindsvater and Carter equations for narrow rectangular notches down to say 20 mm in width and at heads between 20 and 200 mm an appropriate equation is

$$Q = 0.550(b + 0.0025)\sqrt{2g}(H + 0.001)^{3/2} \tag{1}$$

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Flow over weir can be viewed as a particular case of flow through a contracted rectangular flat-crested slit weir. The concept of slit weir is continued in this study using a contracted rectangular flat-crested weir instead of a contracted rectangular sharp-crested weir, which was studied experimentally by Aydin, Ger, and Hincal (2002) and Ramamurthy, Qu, Zhai, and Vo (2007). A slit weir is a very small weir width with a vertical and rectangular opening (Aydin et al., 2002).

A contracted rectangular flat-crested slit weir has been selected in this study due to its simplicity, easy maintenance, and good flow measurement, which is similar to the flow of a rectangular sharp-crested weir. The purpose of the present study is to investigate experimentally the flow of water through a contracted rectangular flat-crested slit weir in order to obtain a discharge equation using the small discharges by varying weir heights.

1.1 Discharge Equations

Assuming ideal conditions, a theoretical discharge equation Q_T , theoretical discharge, m^3/s , can be derived for an uncontracted rectangular sharp-crested weir which is of the form (Russel, 1966):

$$Q_T = \frac{2}{3} b\sqrt{2g}H^{3/2} \tag{2}$$

The actual discharge Q_A over the weir will be in a different form that is given in equation (2) due to the simplified assumptions made in its derivation. A correction must be made to account for the assumptions. Thus, the expression for the actual discharge Q_A can be written as:

$$Q_A = C_d \frac{2}{3} b\sqrt{2g}H^{3/2} \tag{3}$$

The discharge coefficient represents the combined effect of all the parameters that influence the flow over a weir. Equation (3) is widely accepted and commonly used for quantifying the discharge of water over the sharp-crested weir.

2. EXPERIMENTAL SET UP AND PROCEDURES

Experiments were performed in a rectangular stainless steel channel 1100 mm long, 200 mm wide, and 200 mm deep (Figure 1 and 2). The channel entrance is installed with baffle plates to ensure the smooth entry of water in the channel. The slit weirs were made of from Perspex plates 4 mm thick, which is similar to the weir crest thickness (Figure 3). Plasticine was used to prevent water leakage between channel walls and to frame the weir plate’s edges. A rotameter was used to determine the actual discharge measurements. The discharges examined in this study are from 0.00033 to 0.00067 m^3/s. The steel ruler, which has an accuracy of about 5% of the scale, was used to measure the water level. The head measurement section shall be located at a sufficient distance upstream from the weir to avoid the region of surface drawdown caused by the formation of the nape. Ackers et al. (1978) recommended that this should be 3 to 4 times the maximum head upstream of the crest. In this experimental study, the position of head measurement is about $3.7H_{max}$ (390 mm as shown in Figure 1) in which it follows the recommendation.

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The experiment has been repeated for nine different weir plates with the total of 45 runs in which five series of discharge for each weir plate. Water is filled in the feed tank with water from the tap and the pump is started to admit water into the main tank until it discharges over the weir plate. The flow control valve is adjusted to obtain the appropriate discharge reading at the rotameter. The water in the channel is supplied and circulated using water pump at constant speed. Head measurements were replicated thrice, and the mean was used in the analysis. Measurements were conducted for nine different weir heights P (0.035 m, 0.04 m, 0.045 m, 0.05 m, 0.055 m, 0.06 m, 0.065 m, 0.07 m, 0.075 m) in a channel with a width (B) of 0.2 m. According to Aydin et al. (2002), the width of a weir is not classified as a slit if the width exceeds more than 0.075 m. Therefore, following their recommendation, the weir width b = 0.01 m is used for this study.

The liquid used was clean water at 22 ° C, which is considered to possess the standard properties of water such as surface tension σ = 0.0728 N/m, dynamic viscosity μ = 1.002x10^{-3} kg/ms, kinematic viscosity ν = 1x10^{-6} m^2/s, density ρ = 998.2 kg/m^3, and specific weight γ = 9789 N/m^3. The ranges of relevant dimensionless variables covered throughout the experiments are shown in Table 1.

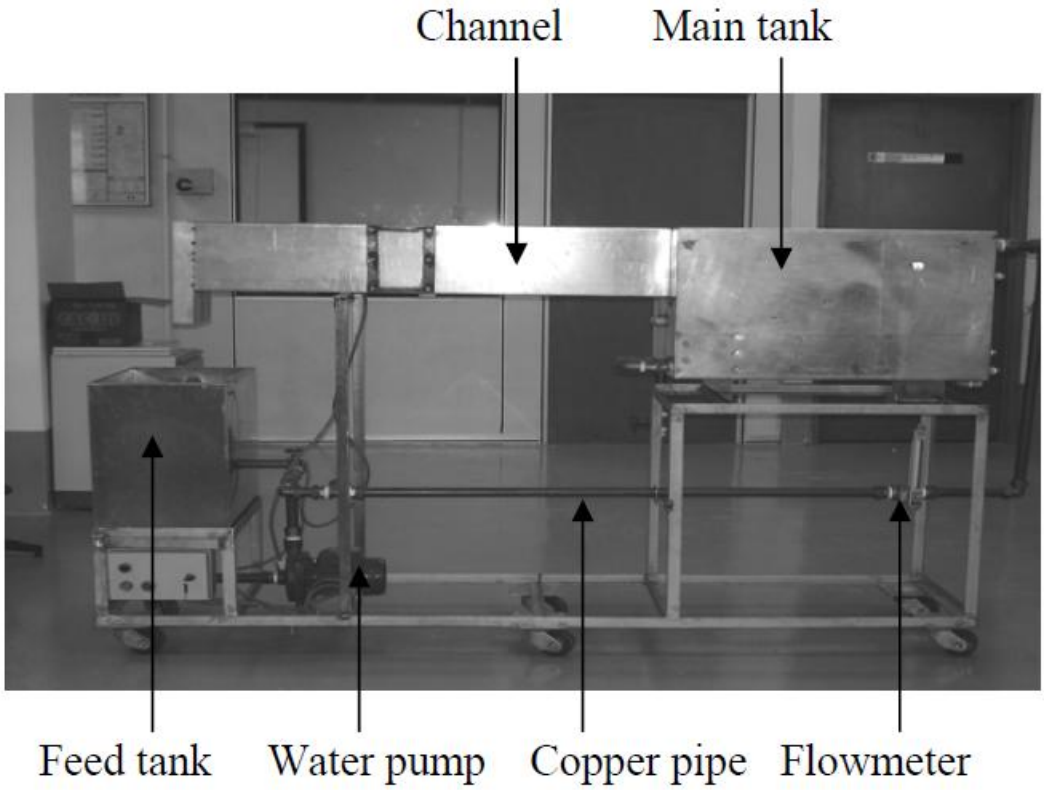

Figure 1: View of an experimental apparatus.

p-ISSN 1675-7939; e-ISSN 2289-4934

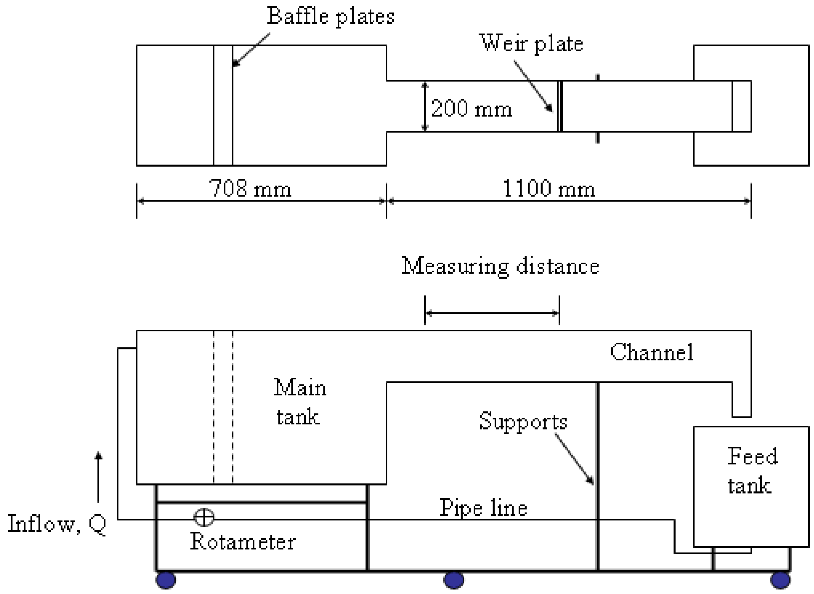

Figure 2: Top and side views of the experimental apparatus.

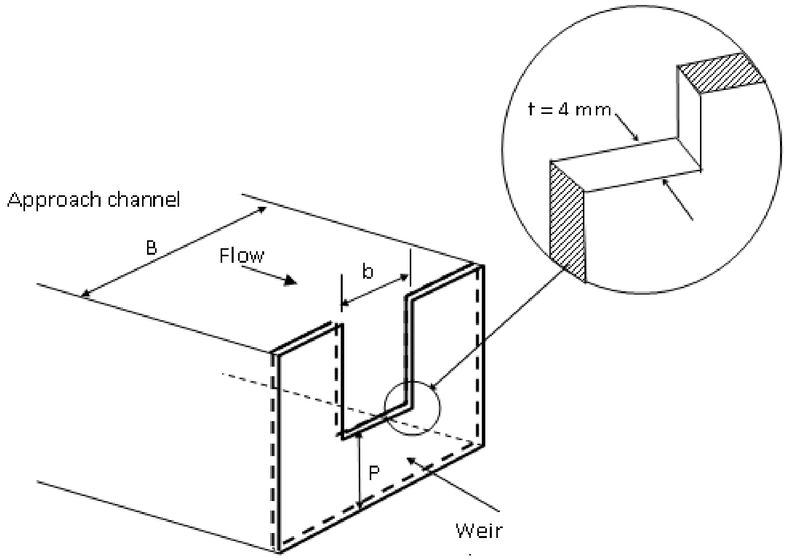

Figure 3: Sketch of a contracted rectangular flat-crested slit weir.

Table 1: Ranges of dimensionless variables.

Variable	Minimum value	Maximum value
t/P	0.053	0.114
H/P	0.853	2.852
H/t	15.750	26.000

p-ISSN 1675-7939; e-ISSN 2289-4934

3. DISCUSSION OF RESULTS

3.1 Discharge Coefficient C_d

From the measured values of actual discharge Q_A and weir head H, the C_d was calculated using equation (3). The C_d values ranged from 0.622 to 0.763; however, the majority of the values were between 0.68 and 0.72. From the statistical results as shown in Table 2, the mean value of C_d is equal to 0.693 and can be written as 0.693 + 0.00414. The value of C_d conventionally applied for the existing weir was 0.62 for the rectangular sharp-crested weir (Igathinathane, Srikanth, Prakash, Ramesh, & Womac, 2006). Thus, it can be observed that the values of C_d for a contracted rectangular flat-crested slit weir fall within the range of values reported for the shapes of a sharp-crested weir. Table 2 also shows the value of mean (0.693) and median (0.694) are equal and the value of skewness (0.124) and kurtosis (0.359) are small. These results show that the occurrence approach a symmetrical bell shape centered around the mean of 0.693, indicating that the data are random or normally distributed and that enough data are obtained to determine a meaningful average value for the C_d (Piaw 2006). In addition, the standard deviation of the mean value of C_d is equal to 0.0275 and its coefficient of variation equals to 3.96%, which is acceptable and it gives an indication that the accuracy of the measurement is good.

Table 2: Statistical results of the discharge coefficient $C_{d.}$

Parameter	Mean, mode and median	Skewness and kurtosis	Standard deviation	Coefficient of variation	Standard error of the mean
Actual C_d	Mean = 0.693 Mode = 0.696 Median = 0694	Skewness = 0.124 Kurtosis = 0.359	0.00275	3.96%	0.00414

3.2 Variation Of Cd With H/P

To study the effect of parameter *H/P* on the discharge coefficient, C_d values were plotted against *H/P* (Figure 4). The graph reveals that C_d decreases with a small negative gradient along with the increase in *H/P*, as represented by the straight line. Thus, C_d is directly proportional to *H/P* and seems to become almost constant at the C_d value of about 0.69. The effect of *P* on C_d does not seem to be significant because the coefficient value of determination R^2 = 0.013 is very small. The best-fitted line of C_d, which was given as a function of *H/P* alone, can be written as:

$$C_d = 0.704 - 0.0064H/P \tag{4}$$

The form of equation (4) is similar to the equation of an uncontracted rectangular sharp-crested weir, where $C_d = 0.611 + 0.08H/P$, which was obtained experimentally in an ideal fluid flow of water by Sturm (2001), but the trend of the relationship is contradicted. The difference between the results may be attributed to the fact that the type of weir crest thickness in their study was not equal to this study.

This result is also supported by Johnson (2000), who reported that the significant dimensionless variable for a rectangular sharp-crested weir is H_t/P. In addition, the C_d value of about 0.64 for the ranges of $0.20 < H_t/P < 1.2$ is also obtained from the graph of C_d versus H_t/P. In this study, for ideal fluid, a constant value of C_d = 0.704 is obtained for the ranges of

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0.85 < *H/P* < 2.85. Therefore, it can be observed that the value of C_d = 0.704 and the equation of C_d as shown in equation (4) for the developed contracted rectangular flat-crested slit weir are acceptable.

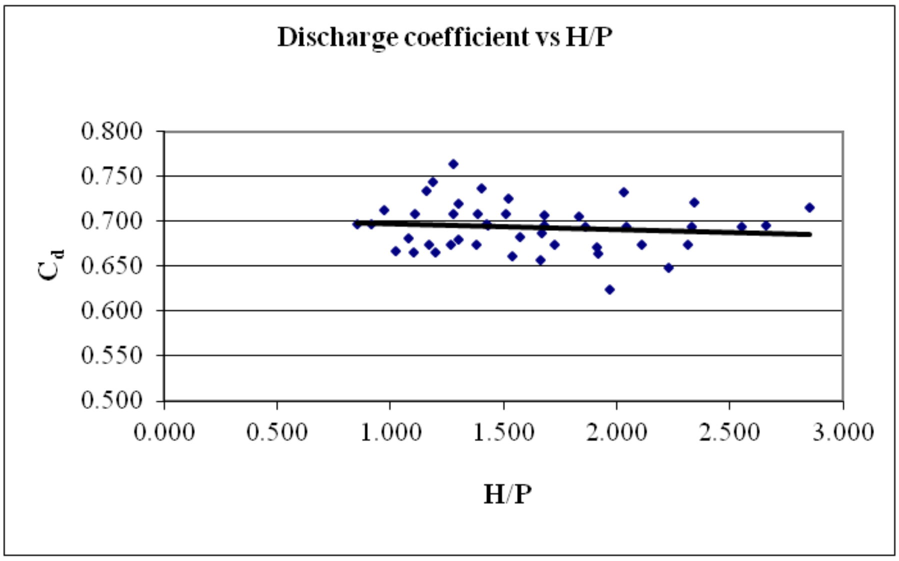

Figure 4: Discharge coefficient C_d plotted against *H/P* at different weir heights *P* for a contracted rectangular flat-crested slit weir.

3.3 Variation Of C_d With H/t

The relationship between C_d and *H/t* is shown in Figure 5. The graph clearly shows that the value of C_d becomes almost constant at an average value of about 0.69, with a faint tendency to increase with a small positive gradient as *H/t* increases, as represented by the straight line. The effect of *P* on C_d does not seem to be significant because the coefficient value of determination R^2 = 0.115 is very small. The best-fitted line of C_d, given as a function of *H/t* alone, can be written as:

$$C_d = 0.632 + 0.0029H/t \tag{5}$$

This finding is supported by the result obtained by Johnson (2000) which shows that the significant dimensionless variable for the rectangular flat-topped weir is H_t/t. Additionally, the C_d value of about 0.64 for the ranges of 1.8 < H_t/t < 4.0 is also obtained from the graph of C_d versus H_t/P. A constant value of C_d = 0.69 is obtained in this study for the ranges of 15.75 < *H/t* < 26.0 without considered the velocity head. Therefore, it can be observed that the value of C_d = 0.69 and the equation of C_d as shown in equation (5) for the developed contracted rectangular flat-crested slit weir are fairly good.

p-ISSN 1675-7939; e-ISSN 2289-4934

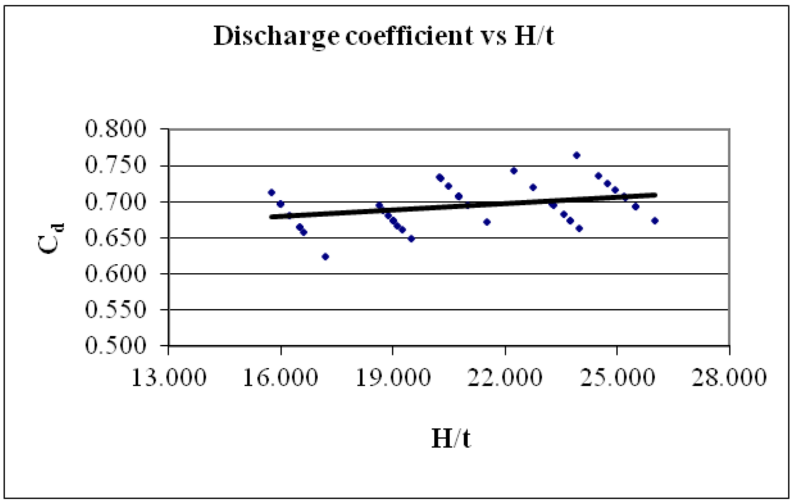

Figure 5: Discharge coefficient C_d plotted against H/t at different weir heights P for a contracted rectangular flat-crested slit weir.

3.4 Discharge Equation

To further investigate the applicability of the formulated equations (4) and (5), analysis of variance (ANOVA) is used to compare the means of the groups, the results of which are shown in Table 3. These types of equations are tested to see which gave the best estimation of the discharge coefficient in which William, Reddy, and Hasfurther (1993) were also used the similar way in the analysis. The mean value of C_d is equal to 0.69. The smallest standard deviation of C_d equals to 0.00315, and the coefficient of variation is equal to 0.454% as given by equation (4). This result is acceptable and indicates that the accuracy of equation (4) is better than that of equation (5). Thus, equation (4) is taken as the estimated discharge coefficient equation, or $C_d(E)$.

Table 3: Results of statistical analysis of discharge coefficient equations

Parameters	**Equation (3)**	**Equation (4)**
Mean	0.694	0.693
Standard deviation	0.00315	0.00913
Coefficient of variation	0.454%	1.32%

The values of actual discharge coefficients, or $C_d(A)$, are compared with the values of estimated discharge coefficients $C_d(E)$ by using Equation 4 as shown in Figure 6. The figure reveals that $C_d(A)$ becomes almost constant with a faint tendency to increase. The relationship between $C_d(A)$ and $C_d(E)$ is very weak due to the small coefficient value of determination R^2 (0.0124). It means that both discharge coefficients are equally good and a constant value of C_d equal to 0.69, as obtained from the experiment, can be accepted.

p-ISSN 1675-7939; e-ISSN 2289-4934

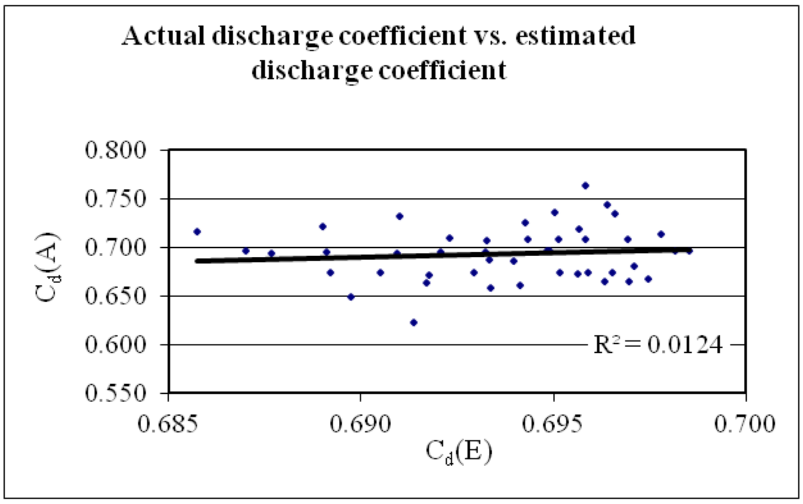

Figure 6: The actual discharge coefficient $C_d(A)$ plotted against the estimated discharge coefficient $C_d(E)$ for a contracted rectangular flat-crested slit weir.

However, the recommendation for a more accurate discharge coefficient equation for water flow over a contracted rectangular flat-crested slit weir is written based on equations (3) and (4) and is expressed as:

$$Q_E = \left(0.469 - 0.00427\frac{H}{P}\right) b\sqrt{2g}H^{3/2} \tag{6}$$

Therefore, equation (6) can be used to estimate the discharge of water over a contracted rectangular flat-crested slit weir for the ideal fluid flow of water with the following limitations: 0.035 m < P < 0.075 m; b/B = 0.050; 0.853 < H/P < 2.852; 15.750 < H/t < 26.000; 6.3 < H/b < 10.4; and velocity of approach is neglected.

4. CONCLUSION

A generalized simple equation for the free flow discharge of water through a weir is presented successfully in an analysis, wherein the discharge coefficient and the discharge equations for a contracted rectangular flat-crested slit weir are obtained. The proposed empirical discharge equation,

$$Q_E = \left(0.469 - 0.00427\frac{H}{P}\right) b\sqrt{2g}H^{3/2}$$

with the accepted constant value of C_d = 0.69 provided a good estimation of the discharge over the contracted rectangular flat-crested slit weir. Therefore, this type of weir can be designed to measure a small range of discharge rates.

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