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Calibration 7" – Cutthroat Flume as New Size for Discharge Measurement at Free Flow Condition

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K E Y W O R D S

Cutthroat flume; throat width; free flow; Empirical formula ; discharge measurement structure; minimal head loss.

A B S T R A C T

This paper aims to conduct a series of laboratory experiments in case of steady-state flow for the new size 7˝throat width (not presented before) of the cutthroat flume. For this size, five different lengths were adopted 0.535, 0.46, 0.40, 0.325 and 0.27m these lengths were adopted based on the limitations of the available flume. The experimental program has been followed to investigate the hydraulic characteristic and introducing the calibrated formula for free flow application within the discharge ranged between 0.006 and 0.025 m3/s. The calibration result showed that, under suitable operation conditions, the suggested empirical formulas can accurately predict the values of discharge within an error ± 3%.

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1. Introduction

Increasing of demands for improving the water management technologies worldwide, leads to the increase need for water measurement structure of low cost with high accurate. Many types of hydraulic structures have been improved for applying to measure the flow in open channels, involving different types of weirs and flumes. The advantages of some types of flumes include; low cost of construction, minimal head loss, and ability for using with different types and sizes of channels. The cutthroat flume (CTF) is one of the flumes have the aforementioned advantageous features. This flume is very useful structure because it is simple but in same time accurate in measuring the discharge. This type of flumes was developed firstly by Skogerboe and his students at the University of Utah in the late 1960s and early 1970s by Skogerboe [1]. The use of a consistent geometric shape has facilitated the development of a general free flow discharge equation for rectangular Cutthroat flumes by Skogerboe.[2].

This flume is characterized by changing the water surface profile dramatically after the section of the throat as compared with flow into the converging section, where at which the surface of the water was almost horizontal. According to this flow profile, the state of the flow across the CTF in the case of modular (Free) flow condition, will be varied from subcritical at the converging section to the critical at the throat then to the supercritical at the diverging section. Ramamurthy [3] suggested equation for estimation the discharge through CTF in free flow condition, by which the CTF discharge for free flow is related solely to the head at the upstream. Because of this correlation the simplicity was achieved for this type of structures. The formula of discharge is take the following fom;

$$Q = Cf\, ha^{nf} \quad (1)$$

This form of Equation has been firstly presented by Skogerboe [1], where Cf and nf are the coefficient and exponent for the free flow conditions, respectively. The values of these parameters are depending on the hydraulic conditions and the geometrical characteristics of the CTF. Manekar[4] developed a dimensionless relationship between a discharge and head in case of free flow. The developed relationship is simple to use and convenient with high accuracy. The main influential factor of the geometrical characteristics, as concluded by all the related previous research is the width of the throat, while the length of CTF has a little effect. Therefore, the width/length ratio has been adopted and its impact is studied extensively by the relevant studies Weber [5]. The suggestion a new approach in which condition a single equation was introduced to account the discharge for both free and submerged flow condition by Torres and Merkley [6].

Through a series of studies carried out by Skogerboe and his team, the last extensive one was for width / length ratios of 1: 9, 2: 9, 3:9 and 4:9 with width 2″, 4″, 6″, 8″, 10″, up to 48,″which studied by Skogerboe and yang (1993) cited by Temeepattanapongsa [7].

In the present study the size 7"(0.1778 m) throat width has been adopted in experimental program with five different lengths 0.535, 0.46, 0.40, 0.325 and 0.27m.The choosing of these length were to give throat width / length ratios 3:9, 3.5: 9, 4:9, 5:9 and 6:9. The first and the third ratio are standard as recommended in literature, whereas the others are new it adopted based on present study.The aim is to calibrate new empirical formulas for discharge of free flow conditions.The measurements in this study were done using the point gauge.

2. Experimental Work

Cutthroat flume models were prepared in the hydraulic laboratory of the Civil Engineering Department, University of Technology-Iraq. Then installed into laboratory flume of cross-section 0.3 m in width and 0.3 m in depth, and its length 15 m, as illustrated in Fig.1. The water was delivered to the flume through 0.1m in diameter pipe, and the discharge is regulated by using a valve attached on the rotameter flowmeter which calibrated with the aid of an ultrasonic flowmeter.

A point gauge on a moving trolley was utilized for measuring the depth of water at a desired location along the centerline of the CTF. The tail gate of the laboratory flume was fully opened to facilitate achieving a free flow downstream the CTF.

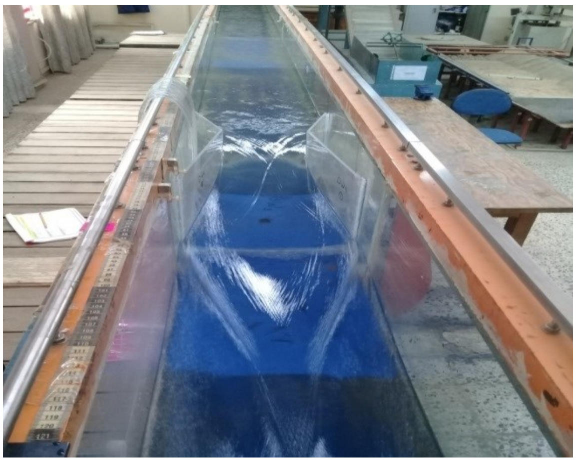

Figure 1: 7"- Cutthroat flume under operation.

3. Models Used

The CTF was designed based on standard configuration as shown in Fig.2 for width 7″ (0.1778 m) and manufactured for five different length. As mentioned previously, these lengths were selected to give two standard width / length ratio along with three new, not investigated before as listed in Table I.

Table I: Details of models undertaken

Model No.	W/L	L(m)	L1(m)	L2(m)	B(m)	Type of flume
CT1	3/9	0.535	0.18	0.355	0.30	Standard
CT2	3.5/9	0.46	0.15	0.31	0.28	New
CT3	4/9	0.40	0.13	0.27	0.27	Standard
CT4	5/9	0.325	0.11	0.215	0.25	New
CT5	6/9	0.27	0.09	0.18	0.24	New

The upstream (ha) and downstream (hb) flow depths were measured at the centerline utilizing the point gauge. The distance from the throat section to the head at inlet ha is represented by the length (La), whereas the length (Lb) is the distance from the throat section to the location of the head at the outlet, hb. It should be noted that the measurements of hb does not taken into analysis because it does not affect the value of discharge when the free flow condition exists.

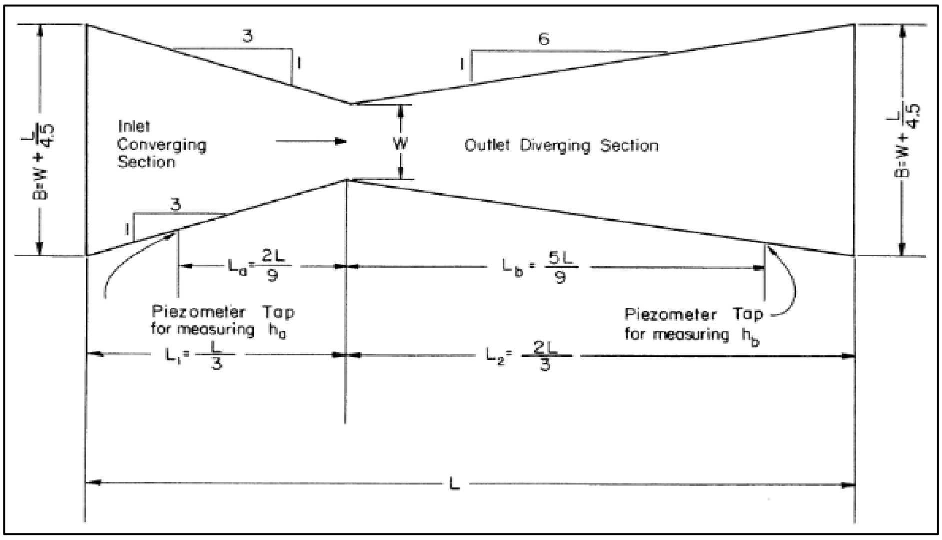

Figure 2: Scheme of the used CTF.

4. Results and discussion

Forty laboratory experiments were conducted and the water surface profile from upstream and downstream are measured by a point gauge. Figure.3 illustrate the water profile for all discharges undertaken at CT5, the decline that noted through the curves refers to the location of the throat.

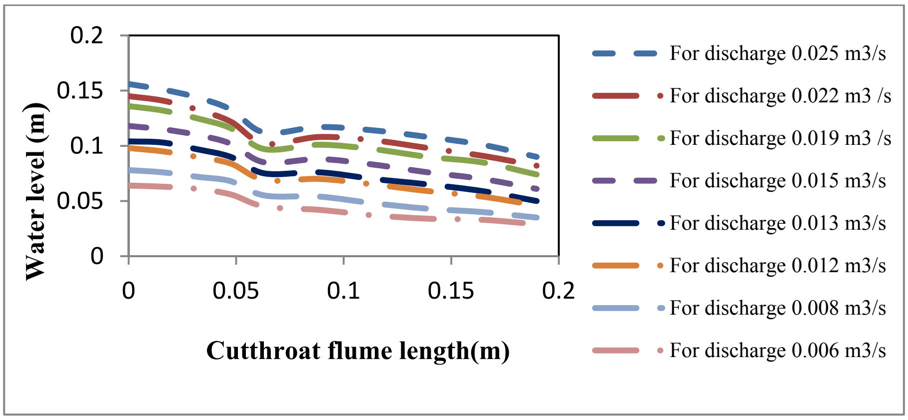

Figure 3: Water profile in case free flow of model W/L ratio 4:9 for all discharge.

I. Rating Empirical Formula

In practice the using of piezometer wells may be clogged because water may contain sediments and debris. For this cause, piezometer wells are not all times the best option. In such a case, to measure the depth of flow, there is an alternative method like the measurement scale attached to the sidewall or using a point gauge. In the current work, the point gauge was utilized in measuring the depth of the flow. By analyzing the measured data, the rating curve of the free flow is prepared and plotted in Fig.4, and its related empirical formulas for the free flow is;

$$Q_f = 0.3414\, h_a^{\,1.516} \qquad (2)$$

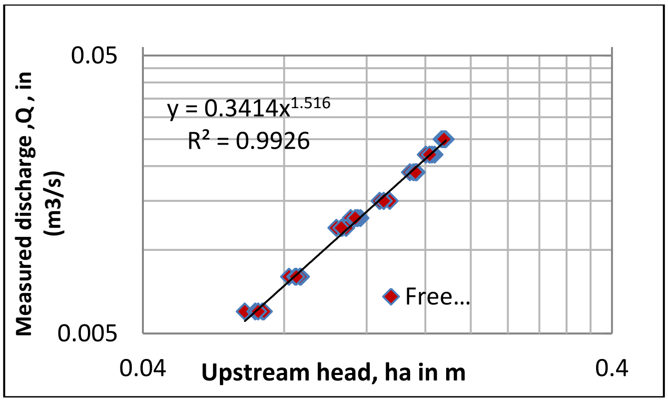

Figure 4: Calibration curve of the free flow condition using the gauge data.

The calculated discharges using Equation (2) are compared with the observed as shown in Fig.5. The calculated data is in good agreement with the observed, where the discrepancy ratio is located within the ±3%.

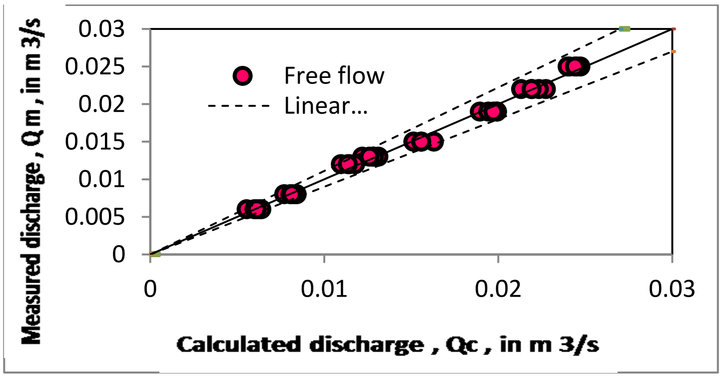

Figure 5: Comparison of calculated data using Equation (2) with observed data (gauge data).

On the other hand Equation (2) is also compared with the equation which proposed by Temeepattanapongsa [8] for free flow condition. The comparison was made by using the result obtained in the present study for application . Fig.6 shows the results of the comparison. It can be seen from Fig.6 that equation(2) match well with Temeepattanapongsa[8], however since the equation proposed in the present is specific only for (7″) throat width Cutthroat flume, the present work proposed equation matches better here.

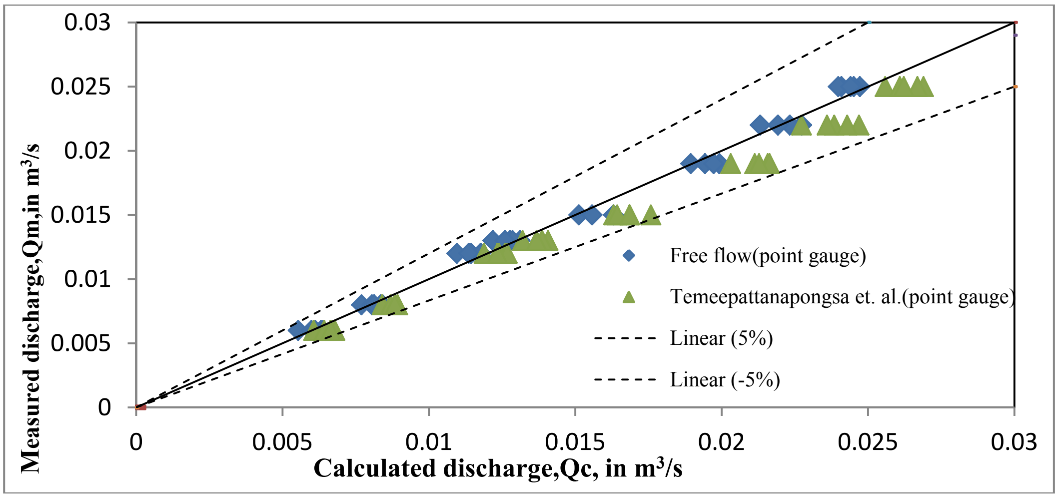

Figure 6: Comparison of developed equation with the work of previous researchers.

II. Dimensionless Relationships for Cutthroat Flume under Free flow Condition

The discharge through Cutthroat flume basically depends on upstream head under free flow condition, and the significant dimensions of the structure. Therefore, functionally, the discharge can be expressed as;

$$Q=f(h_a, L, W, g) \qquad (3)$$

Where Q = discharge; ha= upstream head; L= length of the flume ; W = throat width of the flume; and g = acceleration due to gravity.

The final form of the formulation by using the Buckingham π-theorem of Dimensional analysis

$$\frac{Q}{L^{2.5}\times g^{0.5}} = f\left[\frac{ha}{L}, \frac{W}{L}\right] \qquad (4)$$

If take the influence of throat width into consideration of dependence variable, Equation(4) will be;

$$\frac{Q}{L^{1.5}\times g^{0.5}\times W} = f\left[\frac{ha}{L}\right] \qquad (5)$$

The dimensionless form of the discharge, can be represented by QL and dimensionless head is represented by ha/L. The dimensionless discharge can be expressed as the power function with a dimensionless head,

$$Q_L = K\,(h_a / L)^n \qquad (6)$$

Where the coefficient (K) and the exponent (n) can be found through a regression analysis. The Regression analysis is carried out using 40 experimental data points measured by the point gauge then the following equation was obtained for R2 =0.9964 and the related curve is shown in Figure.7.

$Q_L = 0.6278 (h_a / L)^{1.5492}$ (7)

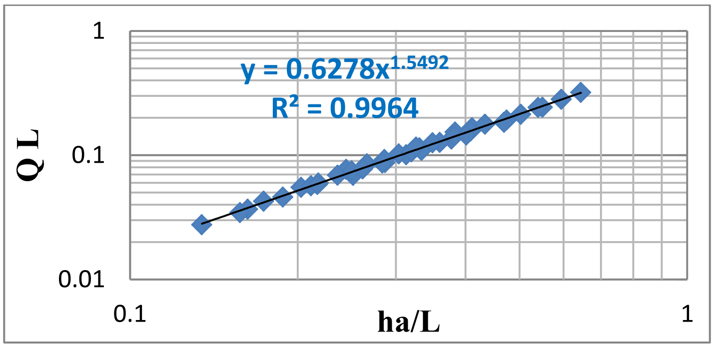

Figure 7: Variation of QL with ha/L based on the experimental data.

5. Conclusions

In this study, the CTF is designed, calibrated, tested, and the best fit equation are presented for free flow of the some data and valid for this channel only and under the limit of discharges. The discharge used for experimental work are ranged between 0.006 to 0.025 m3/s. Based on the laboratory experiment results, an equation was proposed for the data measured by the point gauge it simulated by staff- reading scale in filed. The following can be concluded from this study:

1-The flexibility, simply development, constructing effective, calibration, and economical design of the CTF make it the best choice for measuring discharges in open channels.

2-The proposed equation for discharge calculation in case of the free flow are accurate where the discrepancy ratio was not exceeds ±3%.

3-Calculating the discharge by finding the relationship between dimensionless discharge and dimensionless head under free flow condition.

The measurement accuracy of discharge can be strengthened by increasing the range of calibration flow in addition to avoid the observation errors for the depth of flow and rate of flow measurement.

Acknowledgment

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Nomenclature

W Cutthroat flume throat width (m)

L Cutthroat flume length (m)

L_1 length of the inlet section (m)

L_2 length of the outlet section (m)

L_a distance of stilling well from throat section (m)

L_b distance of stilling well from throat section (m)

h_a flow depth at the inlet (upstream).

Cf, nf free flow discharge parameter and exponent.

$Q_{freeflow}$ free flow discharge (m3 /s).

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