CHARACTERISTICS of COMBINED FLOWOVER WEIRS & BELOW GATES

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ABSTRACT

This paper presents the results of large series of experiments on the characteristics of the simultaneous flow over suppressed sharp crested rectangular weirs and below rectangular gates of sharp edges. A laboratory flume was used to conduct the experiments using a wide range of geometrical dimensions under different flow conditions. The dimensional analysis was employed to correlate the nondimensional discharge to the other relevant geometry and flow parameters. The experimental data were then used to develop a general dimensionless discharge equation for calculating the discharge through the combined notches knowing their geometries and the water level upstream the weirs. The predicted discharge using the nondimensional developed equation agreed well with the experimental data with a deviation of less than 4% in most of the cases.

1. INTRODUCTION

The flow measurements are essential in many fields such as irrigation. Many devices are currently used for this purpose. Among these devices are the weirs either with broad-crest or sharp-crest.. The Most widly used weirs for flow measurements are the sharp-crested ones. They are the most frequently used ones for many decades. The use of weirs as a flow measurement devices in open channels offer simple, reliavle and even accurate method if they installed correctly and maintained properly. The weirs advantages, disadvantages and the requirements for accurate measurements were discussed in different sources, Ackers et al. [1], Bos [2], Herschy [3], and USBR [4,5]. The specifications, installation procedures and discharge formulae for sharp crested (or thin-plate) weirs are described carefully in detail in British Standards Institution, part 4A, BSI 3680 [6]. The discharge equations for the rectangular thin-plate weirs were presented in the literature, Kindsvater and Carter [7]. Swamee [8] presented a generalized discharge equation for rectangular weirs. One of the weirs demirts is they need to be cleaned of sediment periodically and kept clean of weeds and trash [4] and One of the weirs merits is they can be combined with other structures like gates. Some of the weirs demirts can be solved if they combined with sluice gates. The sluice gates are used extensively for flow control and water measurement for long time. Several works can be found in the literature concerning the use of sluice gate in discharge measurements Henery [9], Rajaratnam and Subramanya [10], Rajaratnam [11], French [12] and Subramanya [13]. Recently, Swamee [14] presented a generalized discharge equation for the sluice gates based on Henry's curves. One disadvantage of the sluice gates is they retained the floating materials which can be solved if they combined with the weirs. Very few works dealing with the combined overflow and underflow as flow measurement devices are available in the literature, Chow [15], Ahmed [16], Majcherek [17] and Naudasher [18]. Most of the reported studies on the use of this type of structures as flow measuring device are of limited use and only can be used within specific conditions [19]. Negm [19] analyzed the characteristics of the combined flow over contracted weirs and below contracted gates of rectangular shape with unequal contractions. Recently, Alhamid et al. [20] discussed the characteristics of the combined flow over rectangular contracted weirs and below

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inverted triangular weirs. They presented regression equations to predict the flow passing through the structure [21]. Alhamid et al. [22] developed an equation for a common discharge coefficient for the combined flow over triangular weir and below rectangular gate. This coefficient is , then combined with the sluice gate equation to predict the combined discharge with error of less than 4%.For these reasons, this study comes on the line to provide more information on one of these structures. It is planned to investigate experimentally the characteristics of the combined flow over suppressed weirs and below gates. Different geometric combinations are tested and the effect of all the related parameters are discussed. In addition, nondimensional discharge prediction equation is presented and used accurately for estimating the combined flow rate.

2. THEORETICAL BACKGROUND

Figure (1) shows a definitions sketch for the flow over suppressed sharp crested weir and below rectangular gate with sharp edges of the same weir width. The flow equation for the suppressed sharp crested weir can be expressed as:

$$Q_w=\frac{2}{3}C_w b\sqrt{2g}h^{1.5} \qquad (1)$$

where Q_w is the discharge passing over the weir, C_w is the coefficient of discharge of the weir, **b** is the width of the weir crest, **g** is the acceleration due to gravity and **h** is the head over the weir measured at about 4 times the maximum head over the weir.

On the other hand, the flow equation for the contracted gate of sharp edges can be written as:

$$Q_g=C_g bd\sqrt{2g}\sqrt{(d+y+h-h_d)} \qquad (2)$$

where Q_g is the flow rate under the gate, **b** is the gate width which is the same for the weir and C_g is the coefficient of discharge for the gate and h_d is the head downstream the gate.

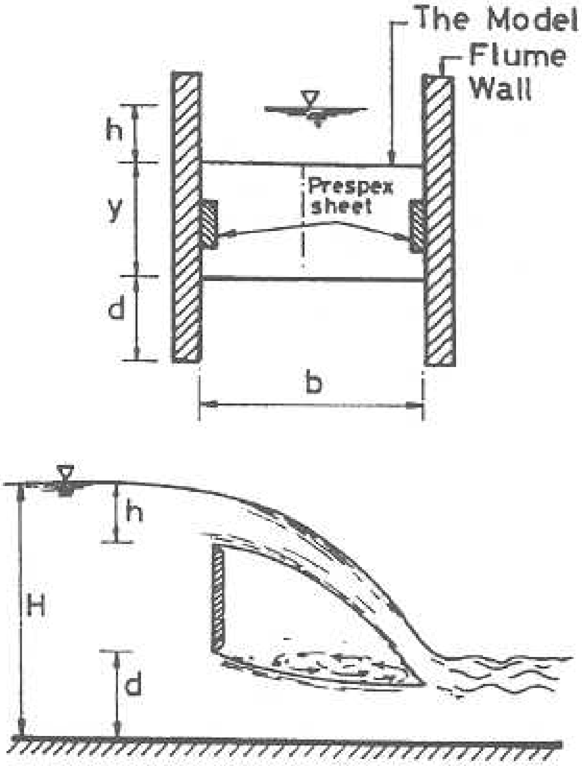

Figure (1) Definition sketch for flow over weirs and below gate combined together.

The flow equation for the combined flow can expressed as following by adding equation (1) to equation (2).

$$Q_c=C_g bd\sqrt{2g}\sqrt{(d+y+h-h_d)} + \frac{2}{3}C_w b\sqrt{2g}h^{1.5} \qquad (3)$$

which can be rewritten as:

$$\frac{Q_c}{\sqrt{2g}bd^{1.5}}= C_g\sqrt{\left(1+\frac{y}{d}+\frac{h}{d}-\frac{h_d}{d}\right)}+\frac{2}{3}C_w\left(\frac{h}{d}\right)^{\frac{3}{2}} \qquad (4)$$

from equation (5) one may deduce the following functional relationship:

$$\frac{Q_c}{\sqrt{2g}d^{2.5}}=f\left(\frac{y}{d},\frac{b}{d},\frac{h}{d},\frac{h_d}{d},C_w,C_g\right) \qquad (5)$$

It should be mentioned that equation (5) could also be obtained by applying the principles of the dimensional analysis.

3. EXPERIMENTAL SET- UP

The experiments of the present study were conducted on a glass sided tilting flume of 9m length working section. The flume bed width as well as maximum water depth is 30.5 cm. The water depths were measured by means of point gauges mounted on the instrument carriages. The discharge was measured by a pre-calibrated V-notch installed in a measuring tank. The measuring tank is located below the outlet of the flume at its downstream end and is connected directly to underground sump tank. The flume is equipped with a sluice gate and a tail gate. The sluice gate is used to control the upstream water level while the tail gate is used to control the downstream water level. The sluice gate is made from galvanized steel plate of 6 mm thick and is bevelled at its lower edge at 45°. A centrifugal pump lifts the water from the underground sump to the flume inlet. The water runs through the flume working section then returns back to the sump tank via the measuring tank.

Sixteen models were tested to achieve the objectives of this study. The models dimensions and details are shown in table (1). The models was made from presbex sheets of thickness 12 mm bevelled from all the edges at 45o with a sharp edges of thickness 1 to 2 mm. The sides of the models were provided with rubber sheets to ensure no leakage from the sides. The models were fixed to the flume at the center using two supports from the downstream side. The supports consists of presbex sheets of width 2.5 cm, length 10 cm and thickness of 1.2 cm fixed to the flume side using silicon. The selection of models material and dimensions are based on the facilities of our laboratory.

Table (1) The tested models dimensions and details

Model	y	d	y/d	b/d
M1	10.00	6.00	1.67	5.08
M2	18.00	6.00	3.00	5.08
M3	10.00	5.00	2.00	6.10
M4	15.00	5.00	3.00	6.10
M5	18.00	5.00	3.60	6.10
M6	10.00	4.00	2.50	7.63
M7	15.00	4.00	3.75	7.63
M8	18.00	4.00	4.50	7.63
M9	18.00	3.60	5.00	8.47
M10	10.00	3.33	3.00	9.16
M11	15.00	3.00	5.00	10.17
M12	18.00	3.00	6.00	10.17
M13	10.00	2.00	5.00	15.25
M14	15.00	2.00	7.50	15.25
M15	18.00	2.00	9.00	15.25
M16	18.00	1.00	18.00	30.50

The test procedure is as follows (a) Adjust the aspect of the flume to the horizontal; (b) Fix the model at the flume center; (c) lower the tail gate to its minimum position and then allow a certain discharge to pass; (d) Waiting until the stability conditions are attained, i.e the upstream water level becomes constant, then the following parameters were measured, the discharge, the upstream water level measured at 40 cm upstream from the weir crest (four times the maximum head over the weir), and the water level just downstream the gate; and (g) This procedure was repeated for each model.

4. ANALYSIS OF RESULTS

The simultaneous flow over weirs and below gates is affected by many parameters as shown by equation (5). The effect of the parameters of equation (5) is investigated and plotted against the dimensionless combined discharge, Q_T

(= Q_a / ⁄ $2gd^{2.5}$). A typical plot is presented in Fig. 2 to show the variation of h/d on the Q_T. From this figure the following points are observed:

(a) Q_T increases with the increase of h /d at particular b/d and y/d. This increase is due to the increase in the upstream head (at particular d). Consequently, the capacity of both the weir and the gate are increased.

(b) Q_T increases with the increase of both b/d and y/d at particular h/d. To demonstrate the effect of y/d at particular h/d and b/d, Figs. 3a & 3b are plotted out of Fig. 2. Theses figures present the variation of Q_T with h/d and y/d at b/d=6.1 (Fig.3a) and at b/d=7.63 (Fig. 3b). It is clear that Q_T attains an increase with the increase of y/d at constant values of b/d and h/d. For the nearer values of y/d, the increase in Q_T is insignificant as for y/d=3 & 3.6 at b/d=6.1 (Fig. 3a) and y/d=3.75 & 4.5 at b/d=7.63 (Fig. 3b). These variations in Q_T with the variation of y/d is mainly due to the significant increase of the vertical distance between the weir opening and the gate opening (if d is kept constant) resulting in a considerable increase in the discharge passed through the gate compared to the flow over the weir (as h/d is also constant). Regarding the variation of Q_T with h/d and b/d at specific y/d, Figs. (4a & b) are prepared. These figures show that b/d has a remarkable effect on Q_T at constant h/d and at y/d=3 (Fig. 4a) and at y/d=5 (Fig. 4b). In this case the increase in Q_T is due to the decrease of **d** which appeared in the denominator in the term Q_T (=Q_a/ ⁄ 2g $d^{2.5}$) and the increase of **y** (to keep y/d constant at constant **b**, **d** and **y** should vary together inversely). This means that the smaller the d value, the higher the term Q_T and consequently the lower the discharge through the gate. Also, the higher the variable **y**, the higher the term Q_T and hence the higher the flow through the gate. As a matter of fact the flow through the gate is a function of both the area of the gate and the upstream head while the discharge of the weir is only affected by the head over the weir.

5. PREDICTION OF THE DISCHARGE

The dimensionless discharge term, Q_T, is found a function of many parameters as h/d, y/d, b/d and h_d/d. For free flow conditions as in the present study, the effect of h_d/d is of no importance on the combined flow and in cases when little submergence occurs it slightly affects only the discharge below the gate. Different empirical forms are tried to fit an equation to the experimental data using the main parameters as regressors. Among the different trials, the following equations were found to give the best fit, maximum multiple coefficient of determination and minimum standard error of estimate.

- For 5 < b/d < 15.25

$$Q_T=2.5123+0.02809\left(\frac{y}{d}\right)^{2.155}\left(\frac{h}{d}\right)^{3.1521}\left(\frac{h}{b}\right)^{-2}+0.87998\left(\frac{y}{d}\right)^{0.155}\left(\frac{h}{d}\right)^{1.521}\left(\frac{h}{b}\right)^{-1} \qquad (6)$$

with $R^2=0.99$ and $SEE=0.826$ for $1.7\le\frac{y}{d}<9$

- For b/d =15.25

$$Q_T=37.3975-1.75279\left(\frac{y}{d}\right)^{0.155}\left(\frac{h}{d}\right)^{1.521}\left(\frac{h}{b}\right)^{-1}++0.06503\left(\frac{y}{d}\right)^{2.155}\left(\frac{h}{d}\right)^{3.1521}\left(\frac{h}{b}\right)^{-2} \qquad (7)$$

with $R^2=0.97$ and $SEE=3.94$ for $5\le\frac{y}{d}\le 9$

- For b/d=30.5

$$Q_T=219.012-3.68\left(\frac{y}{d}\right)^{0.155}\left(\frac{h}{d}\right)^{1.521}\left(\frac{h}{b}\right)^{-1}++0.035\left(\frac{y}{d}\right)^{2.155}\left(\frac{h}{d}\right)^{3.1521}\left(\frac{h}{b}\right)^{-2} \qquad (8)$$

with $R^2=0.988$ and $SEE=16.875$ for $\frac{y}{d}=18$

- For 15.25 < b/d < 30.5

$$Q_T=34.076+0.115\left(\frac{y}{d}\right)^{0.155}\left(\frac{h}{d}\right)^{1.521}\left(\frac{h}{b}\right)^{-1}+0.017\left(\frac{y}{d}\right)^{2.155}\left(\frac{h}{d}\right)^{3.1521}\left(\frac{h}{b}\right)^{-2} \qquad (9)$$

with $R^2=0.988$ and $SEE=14.786$ for $5\le\frac{y}{d}\le 18$

- For 5 < b/d < 30.5

$$Q_T=3.148+1.081\left(\frac{y}{d}\right)^{0.155}\left(\frac{h}{d}\right)^{1.521}\left(\frac{h}{b}\right)^{-1}+0.012\left(\frac{y}{d}\right)^{2.155}\left(\frac{h}{d}\right)^{3.1521}\left(\frac{h}{b}\right)^{-2} \qquad (10)$$

with $R^2=0.991$ and $SEE=8.365$ for $1.7\le\frac{y}{d}\le 30.5$

The computed dimensionless discharge term, Q_T is computed using either equation (6) for $5 \leq b/d \leq 15.25$ and equation (7) for $b/d=15.25$ as typical examples and plotted against the experimental data in Fig. 5. From this figure close agreement between the prediction equations and the experimental data can be concluded. Equation (10) covers the full range of the data and it is recommended for rough estimation of the discharge through the device as it gives lesser accuracy compared to the other limited range equations.

6. CONCLUSIONS

A device for measurements of the simultaneous flow below gates and over weirs is proposed. This device comprised of a combined suppressed sharp-crested weir (upper opening) and a sluice gate of sharp edged (lower opening). This device has the advantage of minimizing the difficulties of using either the weir or the gate solely. The effect of the important parameters on the combined discharge are discussed and presented graphically. A discharge prediction equations are presented which give close prediction to the experimental data within the limitations $5 \leq b/d \leq 30.5$,

$1.7 \leq y/d \leq 18$, $0.3 \leq h/d \leq 9.5$,

$0.085 \leq h/b \leq 0.32$. An advantage of the developed equations is they are independent of the coefficients of discharge of either the weir or the gate.

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NOTATIONS

b	width of the flume.
C_d	the discharge coefficient for the combined flow.
C_g	discharge coefficient of the lower opening alone.
C_u	discharge coefficient of the contracted rectangular weir alone.
g	acceleration due to gravity.
d	gate opening.
h	the measured head over the weir.
Q_c	the measured actual discharge for the combined flow.
Q_p	the predicted flow using equations from (6) to (10).
Q_w	discharge over the suppressed rectangular weir alone.
Q_g	discharge below the gate alone.
Q_T	combined discharge (= Q_{To}).
Q_{Tp}	predicted combined discharge.
R^2	Multiple coefficient of determination.
y	the vertical distance between the top most weir edge and the bottom most gate edge.

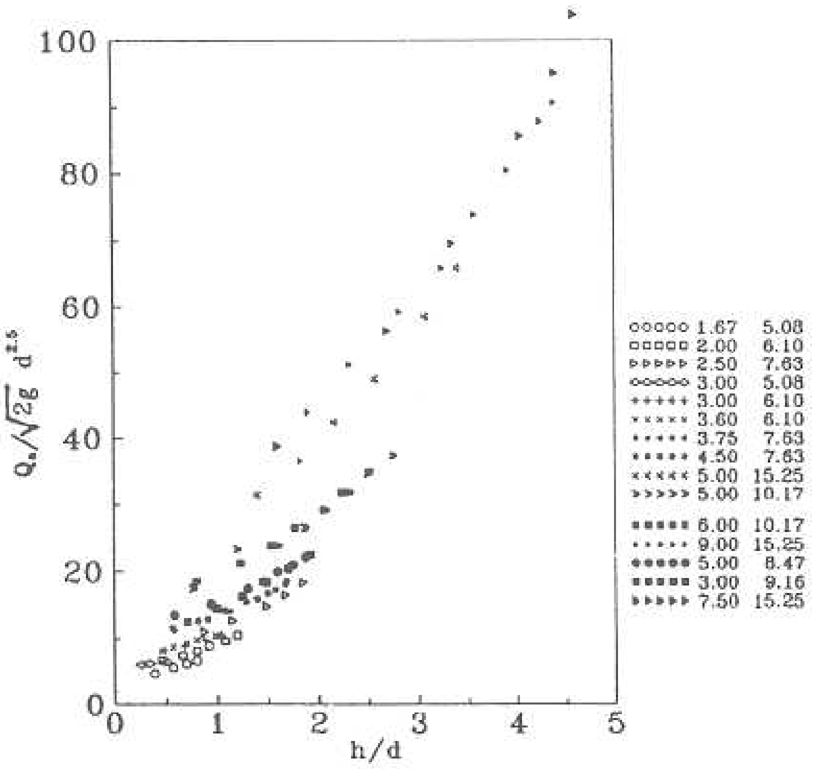

Figure 2. Variation of Q_T ($=Q_e/\sqrt{2g}\ d^{2.5}$) with h/d for different b/d and y/d values.

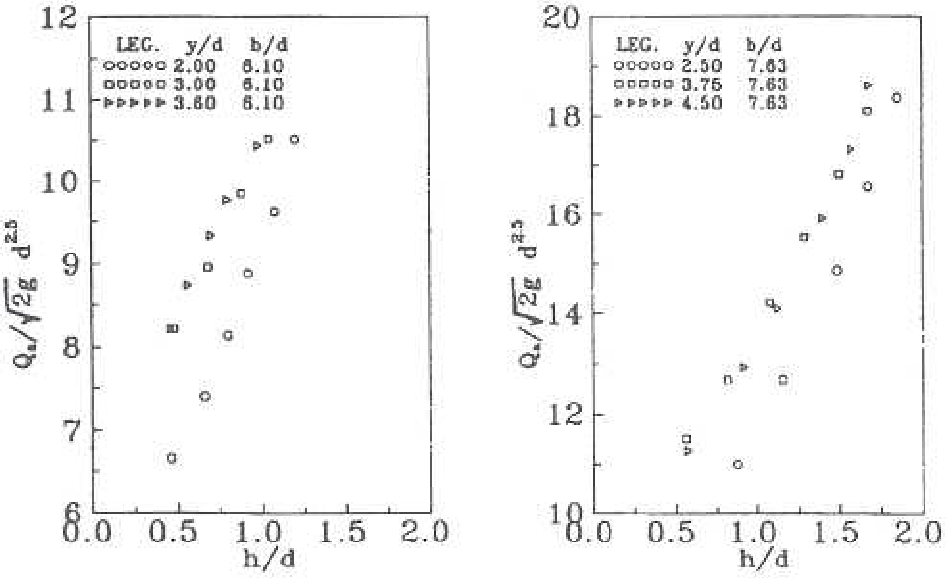

Figure 3. Effect of y/d on the variation of Q_T ($=Q_e/\sqrt{2g}\ d^{2.5}$) with h/d for (a) b/d= 6.1 and (b) b/d=7.63

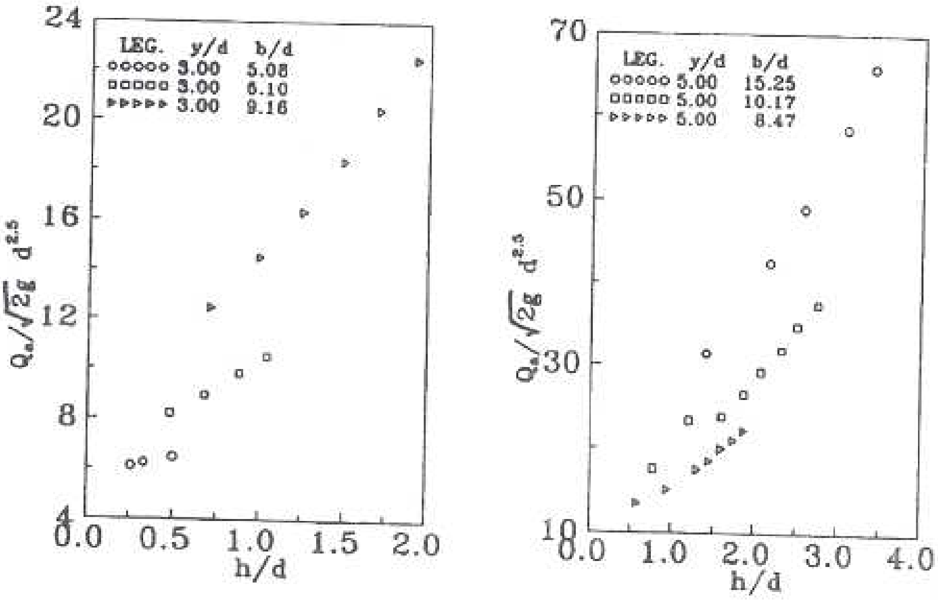

Figure 4. Effect of b/d on the variation of Q_T ($=Q_a/\sqrt{2g}\ d^{2.5}$) with h/d for (a) y/d= 3 and (b) b/d=5

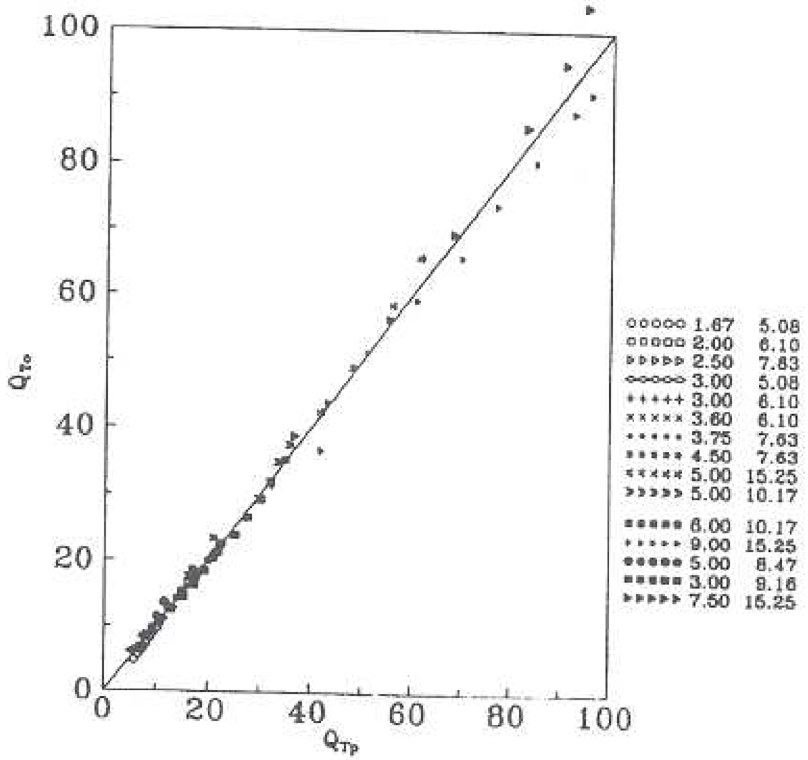

Figure 5. Typical comparison between the observed discharge term Q_{To} and the predicted one using equations (6) and (7).