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CRITICAL WATER DEPTH FEATURES OVER BROAD-CRESTED WEIRS

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خصائص العمق الحرج فوق الهدارات ذات العتب العريض

خلاصة :

يهدف هذا البحث إلى دراسة تحديد قيمة ومكان العمق الحرج للسريان فوق الهدارات ذات العتب العريض ودراسة كافة العوامل المؤثرة وذلك بهدف استخدامه كوسيلة سريعة لتحديد التصرف المار في القنوات المكشوفة. وقد تم إجراء الدراسة في قناة معملية كما تم عمل نماذج للهدار بارتفاعات واطوال مختلفة. وتم إجراء الدراسة لنسبة اختناق للمجرى قيمتها 0.607 وقيم مختلفة لنسبة ارتفاع الهدار على طوله (0.50-0.425) وكانت النسبة بين الضاغط وطول الهدار تتراوح بين 0.10 إلى 0.51 . كما تم استخدام التحليل البعدي في تحديد العوامل المختلفة التي تؤثر على قيمة ومكان العمق الحرج فوق جسم الهدار. وانتهت الدراسة إلى أن العمق الحرج للسريان يتأثر تأثرا كبيرا بأبعاد الهدار وكذا نسبة الضاغط لطول الهدار. وقد أمكن استنتاج معادلات رياضية لتحديد قيمة ومكان عمق السريان الحرج فوق الهدارات ذات العتب العريض وتم عمل مقارنة بين نتائج هذه المعادلات والقراءات المعملية لهذا البحث بالإضافة لقراءات معملية لأبحاث أخرى وكان هناك توافق كبير بينهم. وبذلك يمكن استخدام هذه المعادلات في تحديد قيمة التصرف المار فوق الهدار باستخدام معادلة تربط بين التصرف والعمق الحرج في القنوات المكشوفة.

ABSTRACT

The characteristics of flow over suppressed broad-crested weirs have been extensively studied by old and recent investigations, while for contracted ones, the studies are limited. In the present study, the characteristics of the critical water depth over the contracted weirs were investigated. The effects of the different weir geometrical ratios and different flow parameters on the critical water depth locations were discussed. Experiments were conducted on a laboratory flume and the measured data were analyzed. An empirical equation, in terms of the weir and the flow parameters was developed to predict the critical water depth over the broad-crested weirs. Another empirical equation was also developed to predict the location of the critical water depth over such weirs. A good agreement was found between the developed equations and the experimental observations of the present study and that of others. Hence, the passing flow discharge becomes easy to be determined using one of the developed empirical equations and applying the discharge equation in terms of the critical water depth in a rectangular open channel.

INTRODUCTION

The broad-crested weir is widely used as a flow measurement structure in open channels. This type of weirs is easy to be constructed and installed while, in the reverse its

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accuracy is very affected due to the variations of the discharge coefficient. The specifications of the broad-crested weirs and installation procedures for accurate flow measurements can be reviewed in BSI [2] and USBR [13].

There are many investigations that have been carried out to study the flow characteristics over the broad-crested weirs, especially for the sake of developing empirical equations to determine the discharge coefficient. Woodburn [14] studied the characteristics of the rectangular broad-crested weirs under free and submerged flow conditions, [14]. Surya and Shukla [11] presented an experimental study concerning the features of the 2-D free flow over rectangular weirs having sharp as well as streamlined corners. Flow separation at the upstream edge of a square edged broad-crested weir was analyzed by Moss [5].

For derivation of an empirical expression for the discharge coefficient, many studies were provided, [1,10,12]. Also, the characteristics of the flow over square-edged and round-nosed rectangular broad-crested weirs were studied under free and submerged flow conditions, [9]. The flow feature over a broad crested weir with vertical upstream wall and sharp-crested corner was analyzed experimentally by Hager and Schawalt [3]. The discharge characteristics over the broad-crested weirs have been analyzed using the boundary theory, [4]. Based on a semi-theoretical approach, a discharge equation for the flow over suppressed and contracted broad-crested weirs has been presented by Ranga Raju and Ahmed [8].

Recently, the flow characteristics over broad crested weirs of different contraction ratio at constant weir height-length ratio were studied [6]. Relationships for the coefficient of velocity, coefficient of discharge and critical water depth were obtained. The location of critical depth over the broad-crested weir of constant weir-height ratio was formulated as follows, Fig. (1):

$$\frac{X_c}{L} = 0.4229\,\mathrm{EXP}^{-0.696\left(1.4443\left(\frac{H+P}{P}\right)^{-4.25}\left(\frac{b}{B}\right)^{1.5}\right)} \qquad (1)$$

It was concluded that X_c/L decreases with the increase of b/B for b/B<0.90. But for b/B$\supseteq$0.90, no considerable changes were noticed. This means that the critical water depth occurs mostly at the same location for suppressed broad-crested weir and those of small contraction ratios, b/B$\supseteq$0.90.

Also, for broad-crested weirs of constant contraction ratio (b/B) and of different height-length ratio (P/L), the flow features were studied. Equations expressing the velocity and the discharge coefficients were developed in terms of the different relevant parameters [7]. The obtained relationships were in a form similar to those of [6] as follows:

$$C_V = b_o + b_1\left(\frac{C_d H}{H+P}\right) + b_2\left(\frac{C_d H}{H+P}\right)^2 \tag{2}$$

$$C_d = \alpha_o\left(\frac{H}{L}\right)\chi_1^{\beta_1} \tag{3}$$

$$\chi_1 = 0.607\left(\frac{H}{L}\right)^{\alpha}\left(\frac{H+P}{L}\right)^{\beta} \tag{4}$$

where: b_o, b_1, b_2, α_o, β_1, α and β are regression constants depending on the weir height-length ratio (P/L).

The present study is planned to extend the recent research on the broad-crested weirs, [7]. Therefore, the characteristics of the critical water depth over the contracted broad-crested weirs of constant contraction ratio (b/B) and of different height-length ratio (P/L) were studied.

EXPERIMENTAL WORK

A horizontal rectangular recirculating flume 30.50 cm width, 31.00 cm height and 9.50 m length was used. The flume was equipped with a tailgate to control the tailwater depth. A centrifugal pump was used for lifting the water from the underground sump to the flume inlet. The water flow was running through the flume and then returned back to the sump tank via a measuring tank.

Contracted broad-crested weirs of different height-length ratios, P/L=0.425, 0.429, 0.472, and 0.500 at constant contraction ratio of b/B=0.607 were tested. The head-length ratio H/L ranged from 0.10 to about 0.50. The flow passing discharge was measured by a pre-calibrated V-notch installed in the provided measuring tank. The measuring tank was located below the flume outlet at its downstream end as it was connected directly to the underground sump tank. The water surface profiles were measured starting from 40.0 cm upstream the weir up to the end of the weir using a precise point gauge (up to 0.10 mm accuracy) mounted on instrument carriages. The water depths were measured each 10.0 cm upstream the weir and each 5.0 cm along the weir body. The location of the critical water depth was determined.

ANALYSIS AND DISCUSSIONS

A typical shape of the analyzed water surface profiles for L=40.0 and P=15.0 cm and different flow discharges of 12.833, 11.00, 9.167, 7.33 and 5.50 lit/s were presented in Fig.(2). The critical water depth (y_c) and its location (X_c) as well as the brink water depth (y_b) were measured for each run. Moreover, some of experimental data of other studies, [6], has been used in this study for comparison purposes, as shown in Figs.(3,4,6,7].

The relationship between (y_b/y_c) and (H/L) is shown in Fig.(3). It can be easily noticed that (y_b/y_c) is mostly independent of (H/L) and (P/L), within the range of the present study. The average value of (y_b/y_c) is about 0.714, while it is about 0.705 for suppressed broad-crested weir, [2,8,13]. Strictly, for broad-crested weirs of $0.08<H/L<0.40$, the value of (y_b/y_c) is about 0.718 as the case of P/L=0.50 has a wider range of H/L. For this particular case, (y_b/y_c) is in between the flow over broad-crested weir and that over the narrow crested weir. For narrow crested weir, (y_b/y_c) may be smaller than that of the broad-crested weir as indicated by the three observations lay beyond H/L=0.40.

Moreover, the relationship between $(y_c+P)/P$ and H/L for different P/L at b/B=0.607 is plotted in Fig.(4). In this figure, a linear relationship can be easily noticed between $(y_c+P)/P$ and H/L with increasing trend as H/L increases, for different values of P/L. The form of this relationship can be written as follows:

$$(y_c + P)/P = A + B(H/L) \tag{5}$$

where A and B are regression constants. Their values depend on the value of P/L as given in Table (1). Once the value of the critical water depth is determined, the flow discharge over the contracted broad-crested weir can be computed using a discharge-critical water depth relationship for a rectangular channel.

Another approach may be used via the determination of the location of the critical depth over the broad-crested weir and then measoring the depth at that location. To achieve this purpose, the relationship between X_c/L and P/L is plotted in Fig.(5) to show the variation of X_c/L with P/L for different flow conditions. It can be observed that P/L affects the location of the critical depth. It can be noticed that the value of X_c/L decreases as P/L increases for $P/L<0.450$. As $P/L\supseteq 0.45$, the value of X_c/L increases. Also, Negm and

Alshaikh [6] proved that X_c/L is function of $(H+P)/P$ and b/B. Fig. (6) represents the relationship between X_c/L and $(H+P)/P$ for different P/L at $b/B=0.607$. In this figure, a linear relationship was shown between both variables as obtained before by Negm and Alshaikh [6]. It is clear that X_c/L is decreasing for increasing P/L as long as the weir is defined as broad-crested $(0.08<H/L<0.4)$. When the weir is not well defined as broad-crested as for $P/L=0.50$ or $(H/L>0.4)$, the values of X_c/L are higher than that for other P/L values of the broad-crested weirs. This also is clear in the relationship between X_c/L and P/L of Fig.(5).

TABLE (1)

Constants of Eq. (5)

P/L	A	B	R^2
0.375	0.9709	1.6144	0.998
0.425-0.472	0.9728	1.4358	0.991
0.500	0.9574	1.2840	0.999

Defining (η) as $\{[(H+P)/P]^{-4.25}\ \{P/L)^{1.5}\}$ which is similar to the parameter (χ) in the work of Negm and Alshaikh [6]. The parameter η is defined to include the effects of both P/L and $(H+P)/P$. The relationship between X_c/L and η is shown in Fig.(7) for different P/L at $b/B=0.607$. The relationship between X_c/L and η takes the form:

$$X_c / L = A_1 + B_1 \eta \tag{6}$$

where A1 and B1 are regression constants. Their values depend on the value of P/L as given in Table (2).

Comparing Eq. (5) and Eq. (6), it could be concluded that it is better to use Eq. (5) such that its value of R^2 seems to be higher. Hence, it will predict accurate values of the critical water deptyh (y_c) and consequently, the predicted flow will be of higher accuracy than that predicted using Eq. (5) due to the misleading results for the location of y_c. However, it is highly recommended that more data on the location of the critical depth can be analyzed to provide more general relationship between X_c/L and η or another more relevant parameters.

TABLE (2)

Constants of Eq. (6)

P/L	A_1	B_2	R^2
0.375	0.4178	-0.234	0.891
0.425-0.429	0.3517	-0.197	0.566
0.472	0.4570	-0.178	0.866
0.500	0.3670	-0.206	0.723

CONCLUSIONS

Experiments on broad-crested weirs with constant contraction ratio and varying height-length ratio were conducted. The characteristics of the critical water depth over the considered weirs were investigated. The different parameters affecting the critical water depth locations were discussed. The study conclusions may be classified as:

1. It has been found that the brink water depth over the contracted broad-crested weirs (y_b) is ranged from 0.714 to 0.718 of the critical water depth (y_c). It seems to be slightly higher than that of the suppressed broad-crested weirs, which generally about 0.705
2. The relative location of the critical water depth (X_c/L) decreases as the relative weir height (P/L) increases as long as the weir is defined as broad-crested weir, ($0.08<H/L<0.40$). When the weir is not well defined as broad-crested weir, $H/L>0.40$ or nearly to be narrow crested weir, $P/L>0.40$. the values of X_c/L takes higher values.
3. An empirical equation, in terms of weir and flow parameters has been developed to predict the critical water depth over broad-crested weirs, Eq. (5).
4. Another empirical equation, in terms of weir and flow parameters has been developed to determine the location of the critical depth for such weirs, Eq. (6).
5. A good agreement has been found between the developed equations and the experimental observations of own and others.

Once the critical water depth be determined using Eq. (5) or measured at location obtained from Eq. (6), the passing flow discharge could be easily computed using a discharge equation in terms of the critical water depth in rectangular channels. However, more investigations are recommended for determining the critical water depth specifications over such weirs, but for a wide range of weir and flow parameters.

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NOTATIONS

b = contracted width of broad-crested weir normal to flow direction, (L);
B = flume width, (L);
C_d = coefficient of discharge of the weir, (-);
C_v = coefficient of velocity, (-);
G = acceleration due to gravity, (LT^{-2});
H = head of water over the weir, (L);
L = length of weir in direction of flow, (L);
q = discharge per unit width, (L^2T^{-1});
Q = discharge over the weir, (L^3T^{-1});
P = weir height, (L);
y_c = critical water depth, (L);
X_c = distance between the critical depth location and the weir crest, (L) and
X = parameter defined elsewhere, (-).

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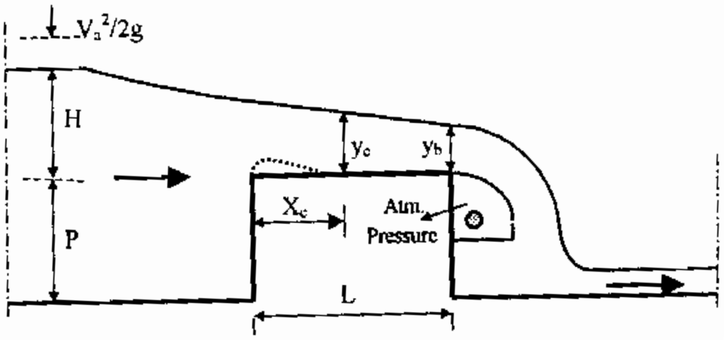

Figure (1) Definition Sketch for Free Flow Over Broad Crested-Weir of Sharp Corners.

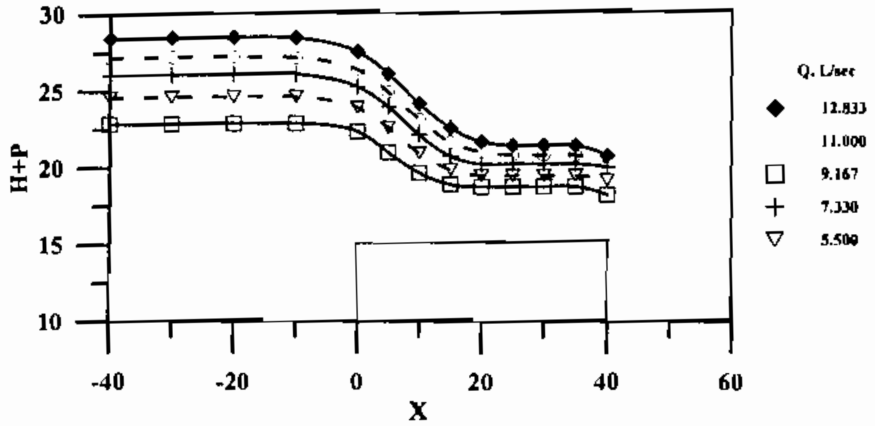

Fig.(2) Typical water Surface profiles for L=40 cm and P=15 cm and different Q.

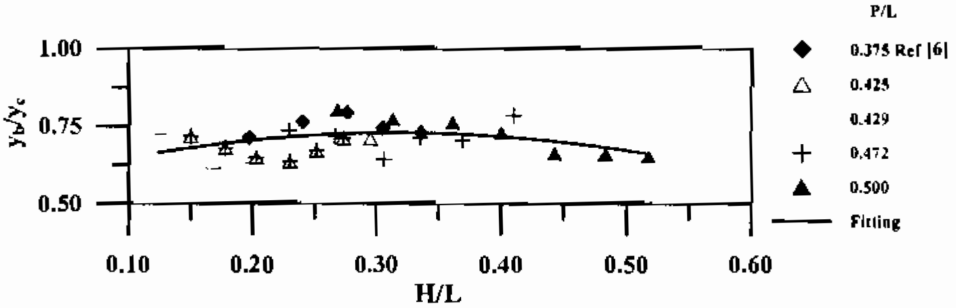

Fig.(3) Variation of yc/yb with H/L for different P/L at b/B=0.607

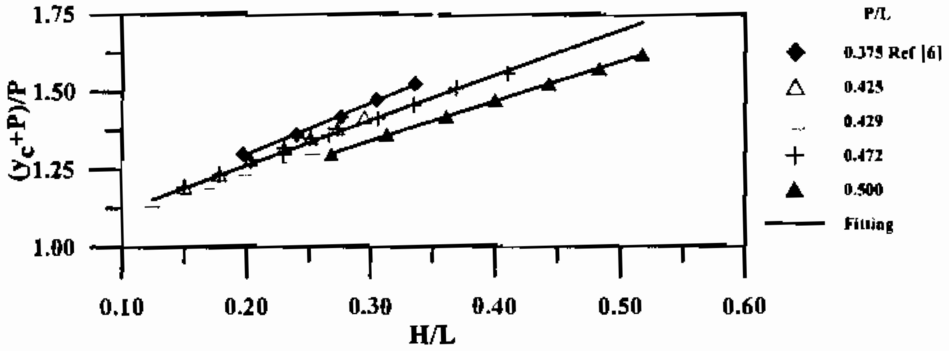

Fig.(4) Relationship between (yc+P)/P and H/L for different P/L at b/B=0.607

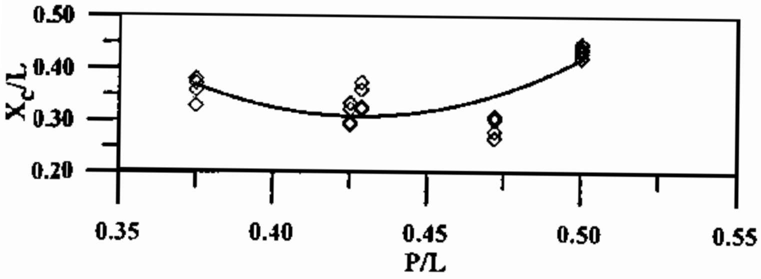

Figure (5) Relationship between X_x/L and P/L
For different flow conditions

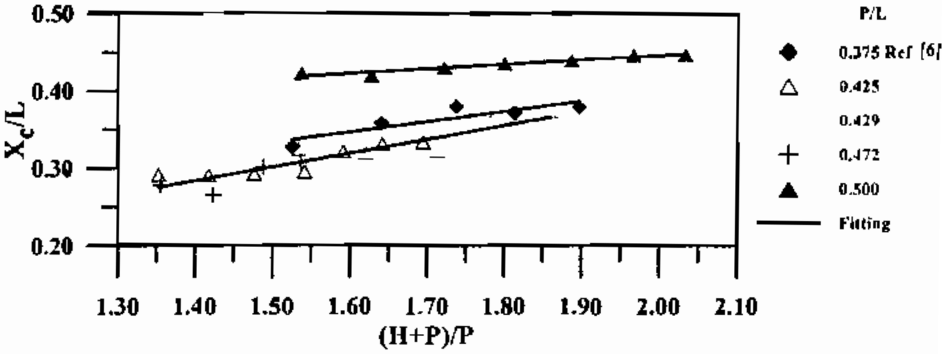

Fig.(6) Relationship between Xc/L and (H+P)/P for different P/L at b/B=0.607

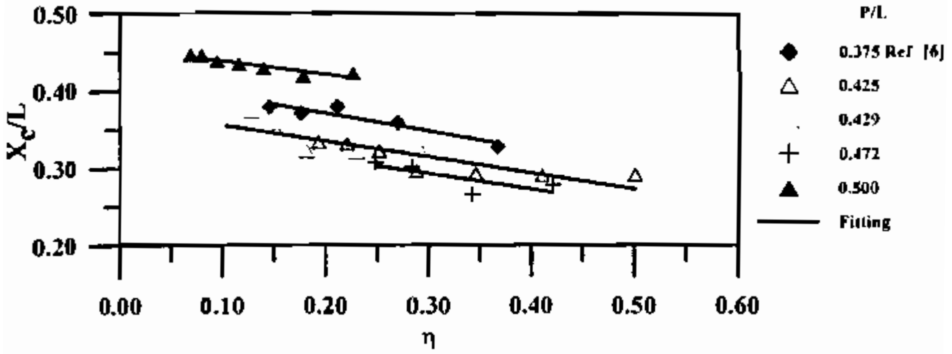

Fig.(7) Relationship between Xc/L and η for different P/L at b/B=0.607