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Discharge Coefficient in Oblique Side Weirs

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ABSTRACT- Side weirs are flow diversion devices that are widely used in irrigation, drainage and urban sewage systems. The present study focuses on the investigation of the effect of oblique side weirs on the discharge coefficient of a side weir under subcritical flow condition in rectangular channels. In this study 106 laboratory tests were conducted and the results were analyzed to find out the influence of non-dimensional parameters on the discharge coefficient of the weirs. The angles of side weirs varied from 0 to 17.5 degrees in six steps, three heights (5, 10 and 15 centimeters) and three lengths (100, 80 and 40 centimeters). Two descriptions of the discharge coefficient (traditional side weir coefficients, C_d, and De-Marchi, C_M), along with different discharges and related parameters were used. According to the results, C_d is more sensitive to b_1/b_2 (ratio of channel bottom widths), whereby C_M is sensitive to L/b_1 (ratio of side weir length to bottom width). The correction formula for estimating the oblique side weir discharge coefficient with a traditional shape shows that a 17.5 degree angle with side wall causes 40 percent change in the discharge coefficient.

Keywords: Discharge coefficient, Side weir, Oblique side weir

INTRODUCTION

Side weirs have been used extensively in irrigation, land drainage and urban sewage systems as a diversion system and are most commonly aligned parallel to the channel or river wall. The hydraulic behavior of overflow structures such as side weirs is quantitatively and qualitatively difficult to comprehend and the reason for this difficulty is different water depths along the side weir and the complication in estimation of the side weir discharge coefficient.

The earliest investigation of the theoretical approach to the hydraulics of flow over side weir in a rectangular channel has been carried out by a number of investigators (4, 6 and 8). Their approach was to compute the water surface profile along the side weir by assuming constant specific energy and discharge coefficients. However, the discharge coefficient varies with distance along the side weir in the direction of flow (14, 9, 1). Although the direction of the side weir is parallel to the flow, the equation of a normal weir is usually used for discharge per unit length as:

$$q=-dQ/dx=\frac{2}{3}C_d\sqrt{2g}\left(Y-H_W\right)^{1.5} \qquad (1)$$

In which H_W= weir height; x= distance along the side weir; Y= flow depth and C_d=weir discharge coefficient (Figure 1.). De Marchi has introduced the coefficient of discharge as follows:

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$$C_M = \frac{3b}{2L}\Phi + c \tag{2}$$

Where L is side weir length, b is width of channel and Φ is varied flow function computed as:

$$\Phi = \frac{2E - 3H_W}{E - H_W}\sqrt{\frac{E - Y}{Y - H_W}} - 3Sin^{-1}\sqrt{\frac{E - Y}{E - H_W}}$$

In which E is specific energy.

Dimensional analysis indicates that C_M is a function of Froude number, weir length, height of the side weir and channel width. The effect of Froude number on C_M was first taken into account by Subramanya and Awasthy (13) and then by others.

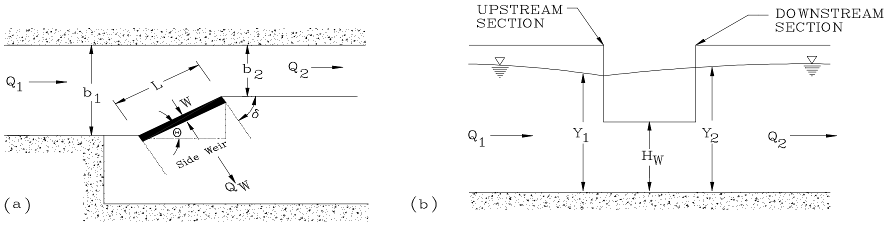

Fig 1. Definition sketch of flow over oblique side weir in rectangular channel (a) Plan and (b) cross-section

A review of the literature shows that a complete analytical solution of the equations governing the flow in side weir channels is not yet possible, and until quite recently, only approximate methods have been suggested, based on experiments conducted over a limited range of the important variables. In addition, most of the reported studies on flow over side weirs are for sharp-crested weirs, aligned parallel to the direction of flow in channels or rivers. From the past investigations, it is found that the C_M coefficient for straight conditions can not have good estimation for oblique side weir, as shown in Figure 2; most equations can not predict the side weir discharge coefficient. Only some equations have smaller relative errors (below ten percent), compared to other equations (9, 16 and 18). However, other equations produce out of range estimates.

A review of the literature indicates lack of reliable information on oblique side weir, so in this study oblique side weirs that perform at 0, 2.9, 4.3, 5.7, 8.6 and 17.5 degree angles together with the direction of flow are considered. The characteristics of discharge coefficients of oblique side weirs are investigated experimentally and are based upon a curve fitting analysis with few attempts in the absence of a computer program.

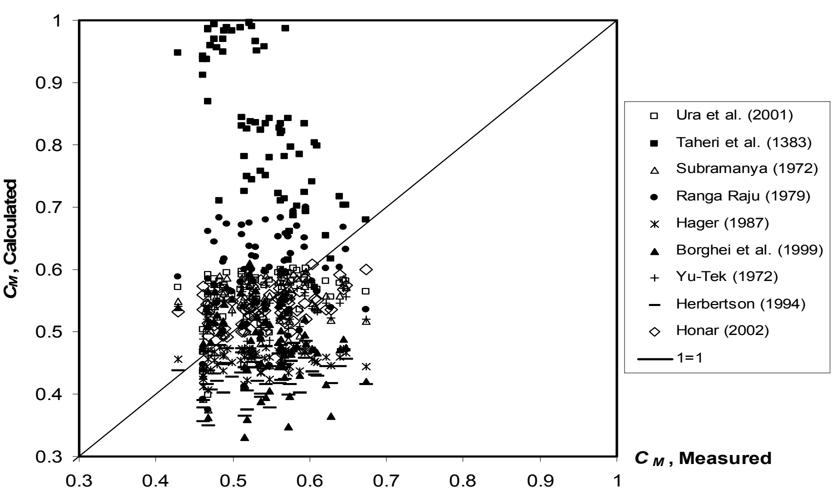

Fig.2. Comparison of discharge coefficient equations results with real discharge coefficient

EXPERIMENTAL SETUP

Tests were conducted in a rectangular channel with internal widths, b=0.35 m and 0.40 m depths and with a bed slope of 3/1000. The channel was 15 m long and the side weir was located at 5 m from the beginning of the channel. To reduce flow turbulence, a flow straightener (made of steel sheets), was inserted at the inlet section. The lateral channel was parallel to the main channel and was 8 m long, 0.6 m wide, 0.40 m deep and had horizontal invert. Two pre calibrated standard V-notches were used to measure the discharge at the downstream end of the lateral and main channels. The side weir length was kept at 1, 0.80 and 0.40 m in the tests. Water depth was measured using a digital point gage in the centerline axis of the channel and also at the length of side weir with an accuracy of ±0.1 mm after steady flow conditions developed in the main channel. The side weir width was kept 0.04 m in all the tests. The experimental tests were carried out for five types of angle oblique side weir (θ= 0, 2.9, 4.3, 5.7, 8.6 and 17.5 degree), three heights of side weir (5, 10, 15 cm) and also three different discharges (20, 30 and 40 liter per seconds). In each experiment, the oblique side was installed at the channel wall and other variables were tested for different stages of discharge.

RESULTS AND DISCUSSION

The measured data was categorized into two groups as side weir with parallel sides to the flow (θ= 0) and oblique side weir that had an angle greater than zero with respect to the flow direction and each group was analyzed to find out the difference.

For the straight side weir conditions, dimensional analysis gives the following dimensionless parameters for the broad crested side weir discharge coefficient in two cases, De-Marchi side weir coefficient (C_M) and traditional discharge coefficient of side weir (C_d).

$$C_M = f(\frac{L}{Y_2}, \frac{V_1}{V_2}) \tag{3}$$

$$C_d = f(\frac{P}{Y_2}, \frac{h_2}{Y_2}) \tag{4}$$

Where L is the length of the side weir, V_1 and V_2 are mean velocity at the beginning and end of the side weir, P is side weir height, h_2 is static head of the flow over the end of side weir and Y_2 is the depth of flow at the centerline of the channel at the adjacent downstream end of side weir.

Many investigators (5, 6), assumed that a linear relationship existed for water surface profiles in the main channel. Therefore, for simplicity, a weighted average of static head (h) over side weir crest was also selected. The Simpson's rule was used to take the mean of the proportional static head of the flow over the side weir.

$$Q_w = \frac{2}{3} C_d \sqrt{2g}(h_m) \tag{5}$$

Where (h_m) can be expressed as follows:

$$h_m = \int_a^b h(x)^{1.5} dx \cong \frac{(\frac{b-a}{3n})}{3}\left[f(a) + f(b) + 4\sum_{i=1}^{n} f_{2i-1} + 2\sum_{i=1}^{n-1} f_{2i} \right] \tag{6}$$

It should be noted that $h_a \ldots h_b$ were measured along the length of the side weir by difference of water depth along the centerline of the channel with the side weir height from the beginning to the end of the side weir with an interval of 0.2 m.

To determine the discharge coefficient, equation 5 is used here. This is a coefficient for the entire flow over the side weir and was based on h_m. The C_d coefficient or dependent variables in the regression model can be obtained as follows:

$$C_d = \frac{Q_w}{2/3 \sqrt{2g} h_m} \tag{7}$$

The above discharge coefficient is then used as the basis for the evaluation of the C_d predicted by the models.

As previously mentioned, for a straight side weir, the discharge coefficient was found to be a function of P/Y_2 and h_2/ Y_2 and with minimum residual sum of squares (RSS):

$$C_d = -9.3708\ E - 2 + 0.517262 \ \frac{P}{Y_2} + 0.740145 \ \frac{h_2}{Y_2} \tag{8}$$

Following Nearing's method (11), sensitivity analysis showed that C_d is sensitive to both independent variables in Equation 8 and there is not any significant difference between the two sensitivity indexes of two variables.

Furthermore, as mentioned before the De-Marchi coefficient (C_M) was found as a function of L/Y_2 and V_1/ V_2 and with minimum RSS:

$$C_M = 0.546277 \quad - 1.187313 \quad E - 2 \frac{L}{Y_2} - \frac{9.2886 \quad E - 2}{V_1/V_2} \tag{9}$$

Sensitivity analysis showed that the two parameters used in C_M calculation do not have any significant difference among their sensitivity index.

To compare the computed straight side-weir discharge coefficient (C_M and C_d) with the observed side-weir discharge using equations (8) and (9), Figures 3 and 4 are presented. From Figures 3 and 4, it is evident that the majority of the data points fall in the error band of ±10%.

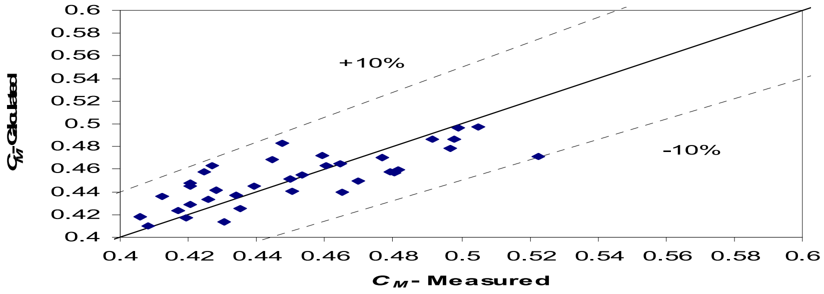

Fig.3. Relationship between measured and calculated side weir discharge coefficient (C_M) in straight side weirs.

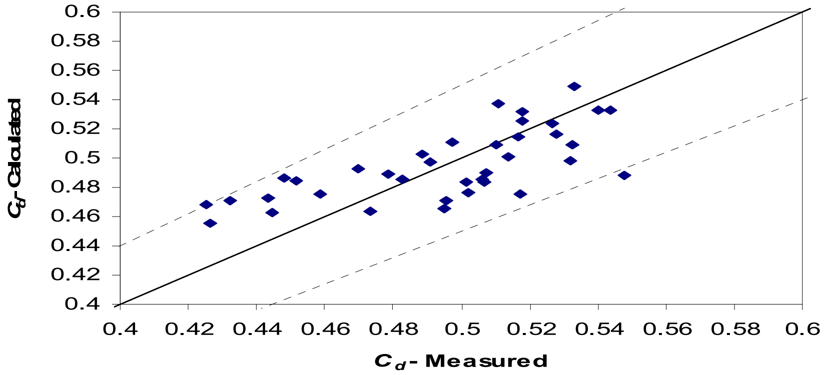

Fig 4. Relationship between measured and calculated side weir discharge coefficient (C_d) in straight side weirs

The next analysis was performed for oblique side weir condition tests. Similar to the calculation for C_M and C_d in straight shape (Equations 8 and 9), results showed that the difference of the actual discharge coefficient in oblique side weir (C_{Mo} or C_{do}) with calculated discharge coefficient for straight shape is a function of six dimensional variables as follows:

$$C_{Mo} - C_M = f(\sin\theta, \frac{h_1}{L}, \frac{h_2}{L}, \frac{L}{b_1}, \frac{V_1}{V_2}) \tag{10}$$

$$C_{do} - C_d = f(\frac{h_1}{L}, \frac{h_1}{Y_1}, \frac{P}{Y_1}, \frac{h_2}{L}, \frac{b_1}{b_2}, \frac{V_1}{V_2}) \tag{11}$$

In these equations θ is the angel between the oblique side weir and the channel wall orientation, and h_1 is the static head of the flow over the beginning of the side weir (other parameters were defined earlier).

The highest correlation and minimum RSS were obtained by using equations 12 and 13 in the above functions (Eq. 10, 11).

$$C_{Mo} - C_M = a\sin\theta + b\frac{h_1}{L} + c\frac{h_2}{L} + d\frac{L}{b_1} + e\frac{V_1}{V_2} + f \tag{12}$$

a=0.51593 b=-1.85465 c=1.29457 d=-0.02847
e=-0.01917 f=0.189228

$$C_{do} - C_d = g\frac{h_1}{L} + i\frac{h_1}{Y_1} + j\frac{P}{Y_1} + k\frac{h_2}{L} + l\frac{b_1}{b_2} + m\frac{V_1}{V_2} + n \tag{13}$$

g=0.64975 i=1.38109 j=1.18239 k=-0.78279
l=-0.05009 m=-0.01306 n=-1.10503

Figures 5 and 6 show a comparison between observed and computed discharge coefficients (C_M and C_d) for oblique side weirs. They show that the majority of the data points fall in the error band of ±10%.

According to Nearing's method (11), sensitivity analysis showed that C_{do}-C_d is more sensitive to b_1/b_2 than other independent variables in Equation 13. Also in equation 12, sensitivity indexes show that C_{Mo}-C_M is sensitive to L/b_1 and no significant difference between other sensitivity indexes of variables was observed.

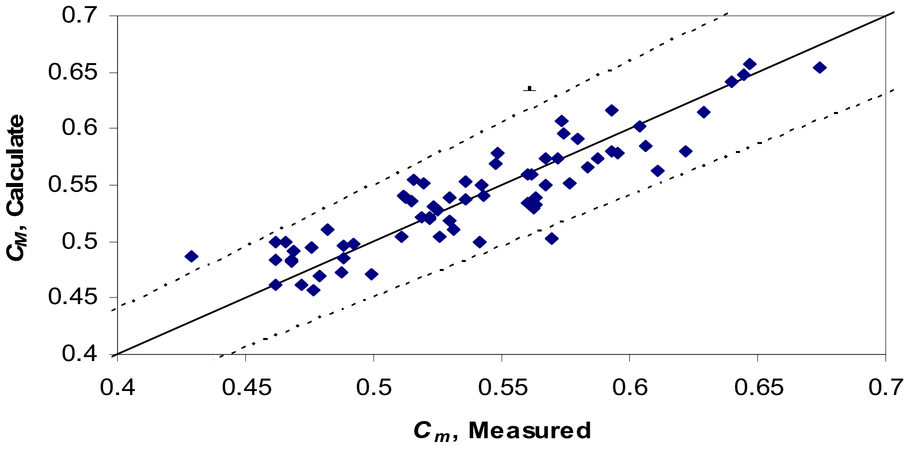

Fig 5. Comparison of measured and calculated oblique side weir discharge coefficient (C_M) using Eq. 9 and Eq. 12

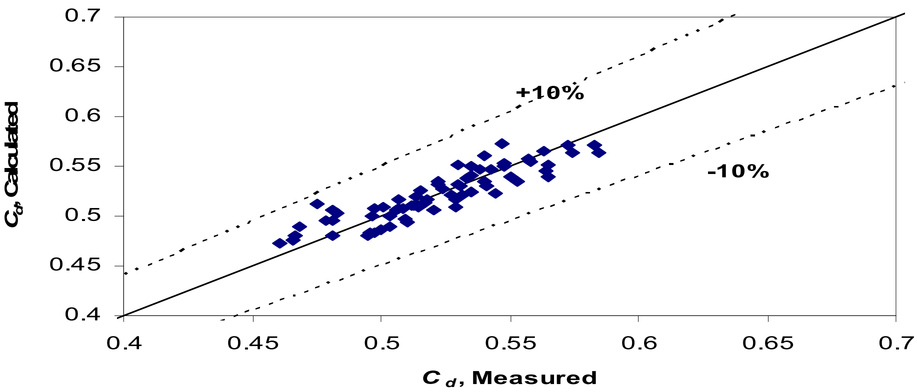

Fig 6. Comparison of measured and calculated oblique side weir discharge coefficient (C_d) using Eq. 8 and Eq.

Considering the importance of the De-Marchi discharge coefficient (C_M) in practical work and the results of the present experiments for side weirs with different off take angles, the relationships between the discharge coefficient and the Froude number at the beginning of the side weir region are shown in Figure 7. In this Figure, for each side weir angle the estimated discharge coefficient for the side weir parallel to the direction of flow is compared to the estimated and actual oblique side weir discharge coefficients. Also in Figure 8, the relationship between C_M and V_1/V_2 is shown for various side weir angles (θ). From Figures 7 and 8, it is concluded that an oblique side weir with a higher angle can achieve a higher value of discharge coefficient (C_M) and in this situation, where the side weir is not parallel to the flow direction, the equation of a normal shape side weir has computational error and could not be used.

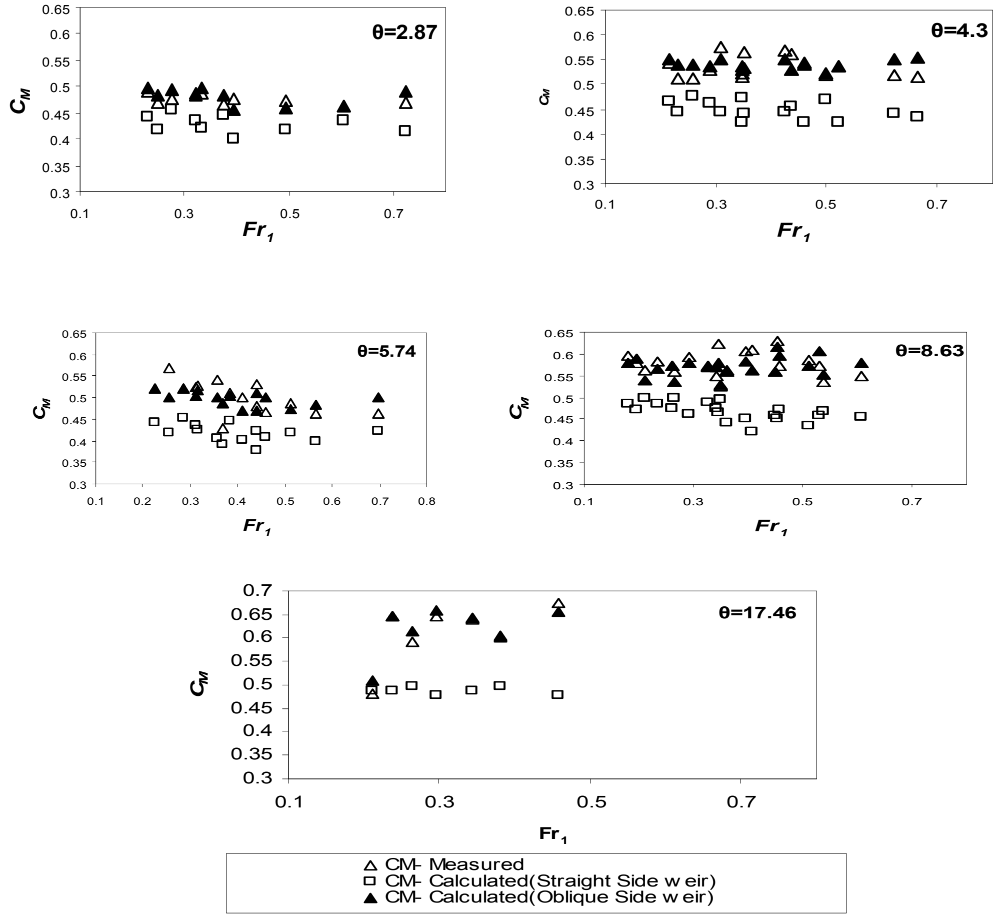

Fig 7. Relationships between oblique side weir discharge coefficient (C_M) and Froude number Fr_1 for various take-off angle (θ)

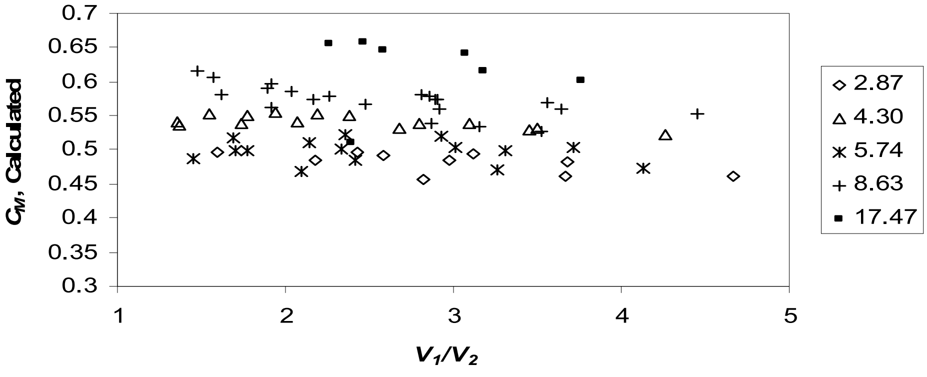

Fig 8. Evaluations of oblique side weir discharge coefficient (C_M) with V_1/V_2 for oblique side weir discharge coefficient (C_M) for different take-off angles (θ)

CONCLUSIONS

A review of the literature on the subject of side weirs shows lack of reliable information on oblique side weirs. This study is an experimental approach for investigating the deflection angle of oblique side weirs with the direction of flow on discharge coefficient. In this experimental study, the angle of the side weir varied from 0 to 17.5 degrees in six steps, three heights (5, 10 and 15 centimeters) and three lengths (100, 80 and 40 centimeters). To find out the effect of oblique side weir angle with the two descriptions of discharge coefficient (De-Marchi, C_M, and traditional side weir coefficient, C_d), different discharges with related parameters were used. The discharge coefficient C_d is more sensitive to b_1/b_2, and C_M is sensitive to L/b_1. Results also show that traditional side weir equations produce more error in calculating discharge coefficients of oblique side weirs. Therefore, equations 12 and 9 for the De-Marchi coefficient of discharge (C_M) and 13 and 8 for traditional discharge coefficient (C_d) are proposed.

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ضریب آبدهی در سرریزهای جانبی مایل

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چکیده- سرریزهای جانبی ، تاسیساتی می باشند که بطور گسترده ای در سیستم های آبیاری ، زهکشی و فاضلاب استفاده می گردند. مطالعه حاضر تحقیقی است که اثر مایل بودن سر ریز های جانبی را برروی ضریب آبدهی, تحت شرایط جریان زیر بحرانی در کانال های مستطیلی بررسی می نماید . در این مطالعه با انجام یکصد و شش آزمایش ، برای سرریز های جانبی مایل با زاویه صفر تا ۱۷در شش مرحله، سه ارتفاع سرریز (۵، ۱۰ و ۱۵ سانتی متر) و سه طول سرریز (۱۰۰، ۸۰ و ۴۰ سانتی متر)، پارامترهای بدون بعد مؤثر برروی ضریب آبدهی برای رابطه دی مارچی (C_M) و رابطه سرریز های معمولی (C_d) تعیین و سپس یک معادله تصحیحی برای تخمین ضریب آبدهی مایل نسبت به حالت معمولی ارائه گردیده است . نتایج نشان می دهد C_d به نسبت عرضهای کانال (b_1/b_2) و C_M به نسبت طول سرریز به عرض کانال (L/b_1) بسیار حساس می باشد. همچنین نتایج نشان می دهد که با ایجاد یک زاویه ۱۷/۵ درجه ای جهت سرریز جانبی نسبت به دیواره کانال، شرایط افزایش آبگیری توسط سرریز جانبی به میزان ۴۰ درصد فراهم می گردد.

واژه های کلیدی : ضریب آبدهی ، سرریزجانبی و سرریز جانبی مایل

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*به ترتیب استادیار و دانشیار

** مکاتبه کننده