E-proceedings of the 38th IAHR World Congress
September 1-6, 2019, Panama City, Panama
doi:10.3850/38WC092019-0155

DISCHARGE CHARACTERISTICS OF TRIANGULAR LABYRINTH SIDE WEIRS (WITH INCLINED BED) LOCATED ON A STRAIGHT CHANNEL

HADI SADEGHIAN[(1)], ALI PARVANEH[(2)], MOHAMMAD A. NEKOOIE[(3)], & MOHAMMAD PARVANEH[(4)]

[(1)] Water and Environment Business Unit, Cardno, Sydney, Australia,
Hadi.sadeghian1982@gmail.com
[(2)] Department of Civil Engineering, Sharif University of Technology, Tehran, Iran,
ali.parvaneh1@gmail.com
[(3)] Department of Emergency Management, Malek Ashtar University of Technology, Tehran, Iran,
ali.nekooie@gmail.com
[(4)] Department of Civil Engineering, Shiraz University, Shiraz, Iran,
mohammad.parvaneh1@gmail.com

ABSTRACT

Controlling the flux of water and wastewater outlet is one of the fundamental principles of the green technology and environmental consideration. Side weir is one of the most common structures to regulate sewer overflow. In order to decrease the length of channel opening with the desired water height, the application of labyrinth side weir has been investigated. The present study, is focused on the investigating the advantages of applying an inclined plate (bed) for triangular labyrinth side weirs. Overall, more than 160 experimental laboratory tests with different hydraulic and geometry variables were conducted. Finally, a nonlinear equation for discharged coefficient of triangular labyrinth side weirs with one cycle and inclined plate (bed) in subcritical flow through a rectangular channel is presented based on the dimensionless parameters. The error analysis for measured values shows an accurate correlation with the results within ±7%.

Keywords: Side weir; Triangular labyrinth; Discharge coefficient; Inclined bed; Experimental model.

1 INTRODUCTION

Side weir, as a flow diverting structure in rivers and channels, is used to control discharge in the main stream. Common types of side weir are installed in the channel side, parallel to the flow direction and with a height of lower than channel height. When water level rises, some portion of the flow are deviated laterally from the weir. This performance will control the discharge and water level in the channel.

Other applications of side weirs include flood control and diversion in the dam reservoirs, flow division and protection against floods in channels and rivers. Moreover, side weir is characterized as one the major hydraulic protective structure in the water conveyance systems.

According to the themes of the succeeding investigations on side weirs, the studies can be classified into four major categories. A number of former studies have focused on identifying the side weirs' discharge coefficient with sub- and/or supercritical approach flow (Jalili and Borghei 1996, Borghei et al. 1999, Azimi et al. 2014 and Crispino et al. 2015). The second group have focused on a progressing subject, e.g. increasing the efficiency of the side weirs, by applying the modified shapes including oblique, triangular, trapezoidal, elliptical and labyrinth side weirs (Parvaneh and Borghei 2009; Parvaneh et al. 2010; Borghei and Parvaneh 2011; Borghei et al. 2013; Emiroglu et al. 2014; Nezami et al. 2015; Aydin and Emiroglu 2016; Aydin and Kayisli 2016; Parvaneh et al. 2016; and Parvaneh et al. 2017). Some others have commonly focused on the effects of the main channel cross-section (e.g. trapezoidal, circular, parabolic or triangular channels) on the efficiency of the side weirs of different geometries (Cheong 1991; Uyumaz 1992; Vatankhah 2012; Vatankhah 2013; and Azimi and Shabanlou 2015). More recent studies have simulated/predicted the side weir discharge coefficient applying computational fluid dynamics and soft computing methods (Emiroglu et al. 2010; Aydin 2012; Vatankhah 2012; Aydin 2015; Parsaie and Haghiabi 2015; and Zaji et al. 2016).

Most of the aforementioned studies were subjected to determine the discharge coefficient of side weirs. In practice, the side weir discharge coefficient is a major factor to be considered. For a given opening length along the side-wall of the main channel, applying the modified shapes such as; triangular and asymmetric labyrinth side weirs results in the increase of the discharge coefficient. Former studies indicated that the angle of flow diversion due to the use of oblique side weirs Y and vertex angle of triangular and trapezoidal side weirs δ_1 along with the upstream approach flow Froude number Fr_1 significantly affect the side weir discharge coefficient (Ura et al. 2001; Parvaneh et al. 2011; Parvaneh et al. 2012; Borghei et al. 2013; Emiroglu et al. 2014; Parvaneh et al. 2016). Until quite recently, approximate methods based on experiments conducted over a limited range of the many variables involved have been used. In many cases, the use of such methods caused very substantial errors in the calculated spill discharge. Partial least square method PLS, artificial neural networks ANN, fuzzy

logic FL and adaptive neuro-fuzzy inference system ANFIS methods are recently widely used for determination of side weir flow discharge coefficient (Ramamurthy et al. 2006; Aydin 2015; and Bonakdari et al. 2015). Borghei and Parvaneh (2011), and Borghei et al. (2013) showed that efficiency of the labyrinth side weirs could be improved by applying a modified shape of oblique-triangular labyrinth side weir.
The main objective of the present study is to investigate the advantages of applying an inclined plate (bed) for triangular labyrinth side weirs. Overall, more than 160 experimental laboratory tests with different hydraulic and geometry variables were conducted and a nonlinear equation for discharged coefficient of triangular labyrinth side weirs with one cycle and inclined plate (bed) is presented.

2 EXPERIMENTAL SETUP

Scaling laws are conditions that must be satisfied to achieve desired similarity between model and prototype. The requirement of mechanical similarity is satisfied for current research. All the experiments for this study were conducted in Hydraulic Laboratory of Sharif University of Technology, Tehran, Iran. Figure 1 illustrates the experimental setup. The hydraulic flume for this study is shown with 0.66m height glass side walls and 0.4m width of metal bed. The length of 7m from the upstream end of the flume let fully developed turbulent flows occur in the approach channel.

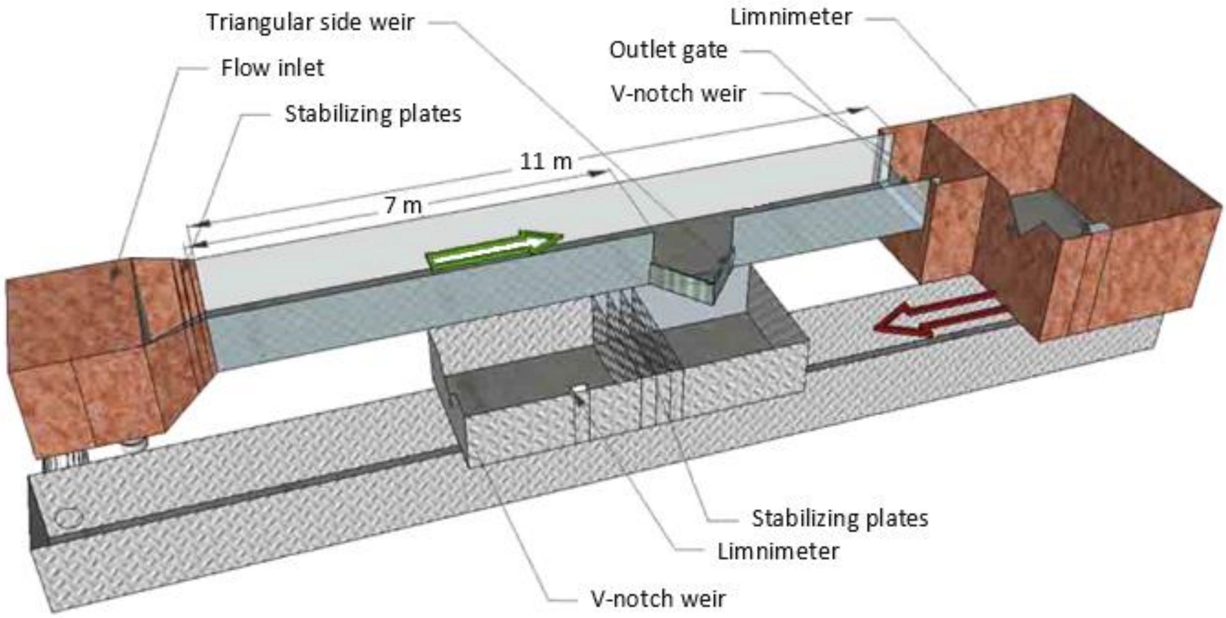


Figure 1. The three-dimensional view of the experimental set up

Figure 2 illustrates a normal triangular labyrinth side weir with one cycle. Where B= channel width (m); L= opening length of side weir (m); l= weir crest length (m); p= weir height (m); δ= vertex angle (degrees); and h_1= flow depth at the upstream end of the side weir (m).

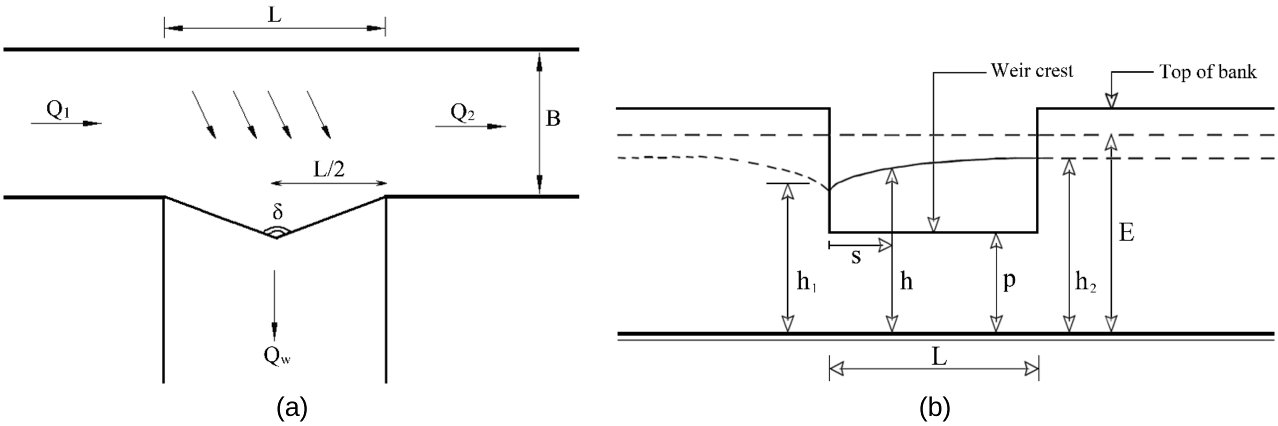


Figure 2. Schematic view of a normal triangular labyrinth side weir; a) plan, b) section.

Since in the normal design the triangular labyrinth side weirs are orthogonal with bed of the channel, the present study introduce a triangular side weir with inclined plate (bed) on flow diversion with respect to the conventional and orthogonal labyrinth side weirs. In Figure 3, you can see the difference between the presented triangular labyrinth side weir and a normal triangular labyrinth side weir.

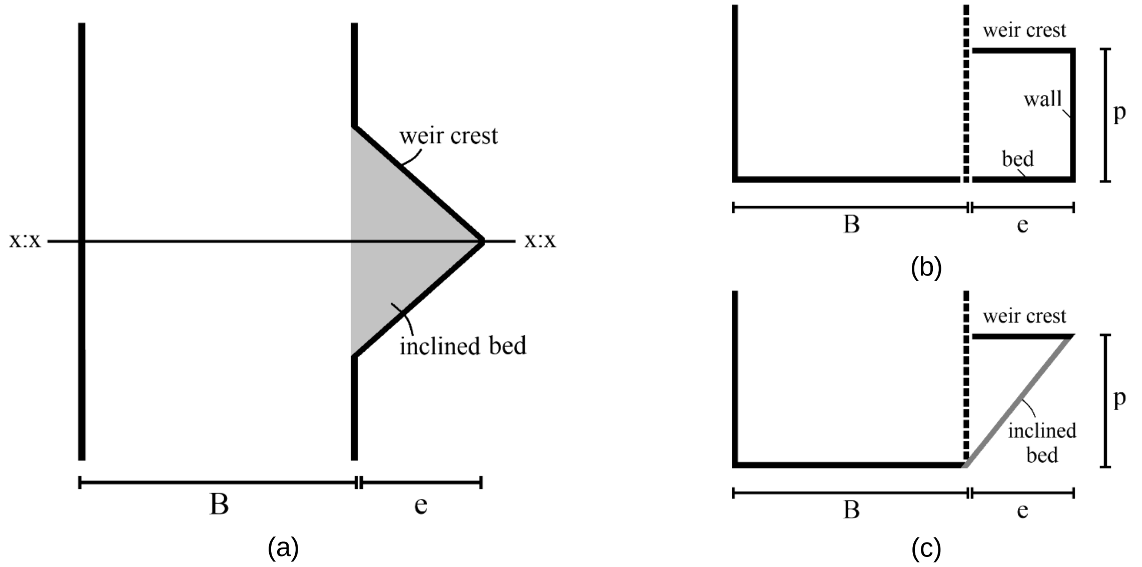


Figure 3. Schematic view of triangular side weirs; a) plan, b) section x:x for triangular side weirs with normal bed; c) section x:x for the presented triangular side weir with inclined bed.

To measure the water level, the flow at the channel center is more stable than the one at the bank of the weir. Thus, the data at the upstream end of the side weir at the channel center was used in the present study (Borghei et al. 1999; Emiroglu and Kaya 2010; Emiroglu et al. 2010). The measurements are done through an electronic point gauge which automatically detects the water level and records the gauge reading. When the weir walls are inclined towards the channel, the vortex effects are minimal; therefore, a flow with fewer disturbances occurs. The investigators conducted over 160 experimental tests and applied the spatially varied flow approach. The range of the test variables is presented in table 1.

Table 1. Range of the variables tested in the present study of triangular labyrinth side weirs with inclined plate

$L(cm)$	$p(cm)$	$\delta(°)$	$Fr_1(-)$	$Q_1(L/s)$	Runs no.
60	5, 7.5, 10, 15	- , 90, 120, 140	0.18-0.62	8.1-38.6	55
40	5, 7.5, 10, 15	60, 90, 120, 140	0.18-0.63	14.3-23.5	70
30	5, 7.5, 10, 15	60, - , 120, -	0.17- 0.59	16.7-21.2	35

The secondary flow appears in the bank of the weir at the downstream end. However, the inclination of the bed prevents turbulent flow before and over the crest. When the head angle (δ) decreases, the side angle increases. Therefore, the flow diversion for side wall of triangular side weirs is increased. Thus, with greater side angle, the slighter and longer bed slop (inclination) provides enough space for flow diversion and prevents any vortex in side weir area. On the other hand, it helps control the inclination of the bed to make side weirs more practical and efficient according to former studies (Prakash et al. 2011).

3 RESULTS AND DISCUSSION

First, the variations of specific energy along the length of side weir were studied. The amount of specific energy at upstream and downstream of weir has been compared in Figure 4. The change percentage of specific energy in the conducted tests was 1.05% which indicates minor change in the specific energy. Therefore, it is possible to assume that specific energy is constant along the weir length.

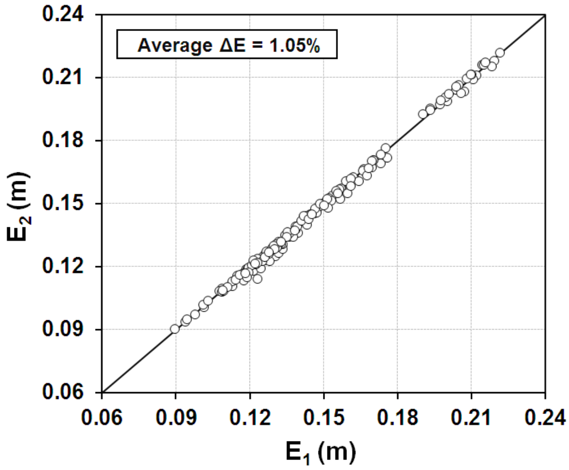


Figure 4. Comparison between E1 and E2

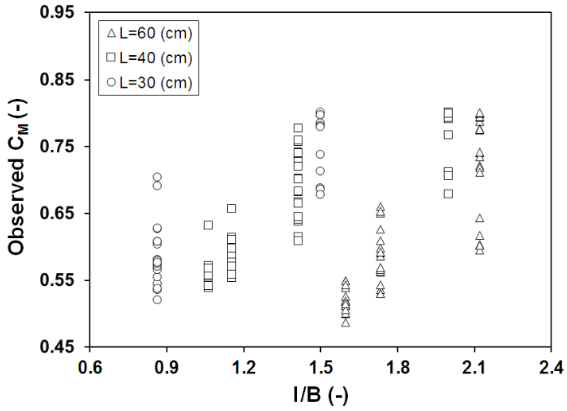
Developing a relation for C_M on the basis of only one dimensionless parameter has a low level of accuracy. Hence, SPSS Software has been utilized to consider simultaneous effects of different dimensionless parameters on C_M. Based on reanalyzing all the available empirical data, given in Table 1, the discharge coefficient for this type of triangular labyrinth side weirs is a function of at least 15 different dimensionless parameters. In SPSS software, independent and dependent variables are determined in such a manner to achieve maximum regression coefficient (R^2). For the sake of deriving an appropriate relation for C_M, different relations were introduced to the software. After running the software, the constant coefficients and regression coefficient are computed in the output. Among these relations, the one with higher regression coefficient is taken as an appropriate relation. To ensure that the relation has adequate accuracy, in addition to (R^2), normalized root mean square error (NRMSE) should be determined. Lower NRMSE corresponds to lower data scattering and higher accuracy of the relation. NRMSE is defined as follows:

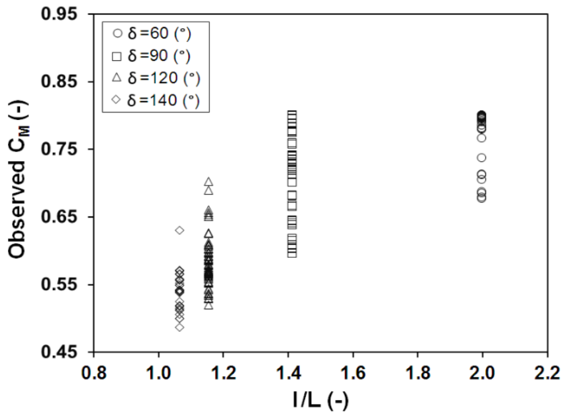
$$NRMSE = \sqrt{\frac{\sum\left(F(x) - f(x)\right)^2}{\sum\left(f(x) - \bar{f}\right)^2}} \quad [1]$$

Where, $F(x)$ is calculated value, $f(x)$ is measured value and $\bar{f}$ is the mean of measured values. Thus, the following nonlinear relation (Eq. 2) is obtained for prediction of the discharge coefficient C_M of triangular side weirs with inclined plate (bed) simply because of its higher accuracy in comparison with other generated equations using the SPSS software.

$$C_M = \left[1.166\left(\frac{p}{h_1}\right)^{0.163} - 0.220\left(\frac{\mathrm{l}}{B}\right)^{-0.048} - 0.378\left(\frac{l}{\mathrm{L}}\right)^{-2.723}\right] \times \left[1 - 0.032\frac{Fr_1}{\sin(\delta/2)}\right] \quad [2]$$

As the most precise equation generated by SPSS software, the nonlinear Eq. [2] is a function of four different dimensionless parameters l/B, l/L, p/h_1, and $Fr_1/\sin(\delta/2)$. Figs. 5(a–d) show the variation of discharge coefficient (C_M) of triangular side weirs with inclined plate (bed) versus these four prevailing dimensionless parameters respectively.





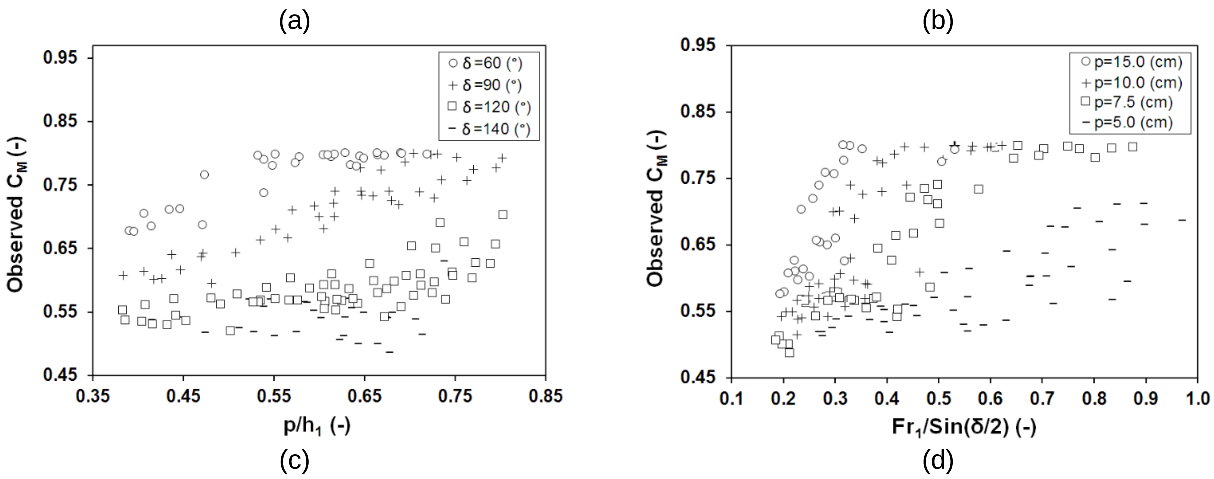


Figure 5. Measured discharge coefficient of triangular side weirs with inclined plate (bed) versus dimensionless parameters; (a) l/B, (b) l/L, (c) p/h_1, (d) $Fr_1/\sin(\delta/2)$

I order to realize the accuracy of Eq. [2], you can see Figure 6 where calculated coefficients are presented against the observed ones. It is apparent that the results are mostly within the range of ±7% which indicates good agreement with the experimental results.

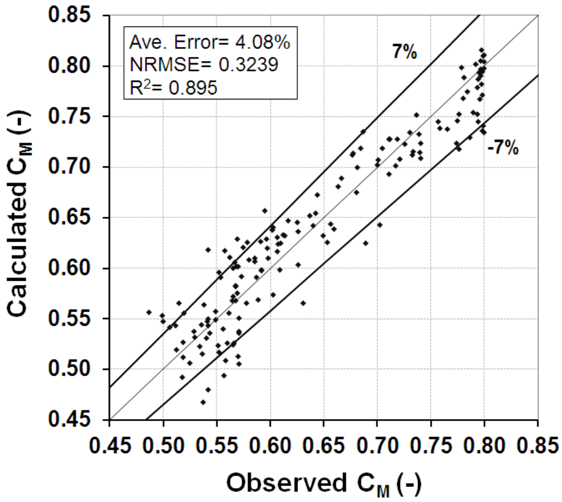


Figure 6. Observed C_M values versus calculated C_M values from Eq. [2]

4 CONCLUSION

The main contributions can be summarized as follows:

-- Like other types of labyrinth weirs, triangular side weirs (with inclined plate) can also significantly increase the lateral discharged water, compared to the normal side weir with the same geometry and flow conditions. They could also be applied as an effective solution for increasing the storage capacity.

-- Application of triangular side weirs (with inclined plate) helps control any fluctuated flow near the downstream end of the side weir which is a significant advantage when the flux deals with sediments or waste materials.

-- The inclination of the bed provides stable conditions for secondary flow and helps control separation zone.

-- On the contrary to normal labyrinth side weirs, this type of inclined labyrinth side weirs prevents any rise of the vortex near the side weir crests.

-- The vertex angle of the inclined labyrinth side weir can act as a control parameter. It means that when δ is between 60-140 degrees, the lower value for δ present the higher value for C_M.

-- Increasing the height of triangular side weirs (with inclined plate) leads to a decrease in their performance.

-- Finally, nonlinear relation Eq. [2] was introduced for prediction of the discharge coefficient C_M of triangular side weirs with one cycle and inclined bed.

ACKNOLEDGMENTS

The authors wish to thank Prof. M. R. Jalili Ghazizadeh for supporting this project with his precious advice and help that made this paper publishable. Special gratitude goes to Sharif University of Technology for supporting this study.

NOTATION

The following symbols are used in the present discussion:

$B=$ width of main channel
$C_M=$ discharge coefficient for side weir
$E=$ specific energy
$Fr=$ Froude number in the channel
$g=$ acceleration due to gravity
$h=$ flow depth at section s
$L=$ length (width) of side weir
$l=$ weir crest length
$p=$ weir height
$Q=$ discharge in the main channel
$Q_w=$ discharge over side weir
$q=$ discharge over side weir per unit length
$s=$ distance from beginning of side weir
$V=$ velocity in main channel
$x_i=$ independent variables
$\delta=$ vertex angle

Subscripts
1 upstream condition
2 downstream condition

REFERENCES

Aydin, M. C. (2012). “CFD simulation of free-surface flow over triangular labyrinth side weir.” Advances in Engineering Software, 45(1), 159–166.

Azimi, H., and Shabanlou, S. (2015). “The flow pattern in triangular channels along the side weir for subcritical flow regime.” Flow Meas. Instrum., 46, 170–178.

Borghei, S., Jalili, M., and Ghodsian, M. (1999). “Discharge Coefficient for Sharp-Crested Side Weir in Subcritical Flow.” J. Hydraul. Eng., 125(10), 1051-1056.

Borghei, S. M., Nekooie, M. A., Sadeghian, H., and Jalili, M. R. (2013). “Triangular labyrinth side weirs with one and two cycles.” Proc. Inst. Civ. Eng., Water Manage, 166(1), 27–42.

Borghei, S. M., and Parvaneh, A. (2011). “Discharge characteristics of a modified oblique side weir in subcritical flow.” Flow Meas. Instrum., 22(5), 370–376.

Cheong, H.-F. (1991). “Discharge coefficient of lateral diversion from trapezoidal channel.” J. Irrig. Drain. Eng., 117(4), 461–475.

Crispino, G., Cozzolino, L., Della Morte, R., and Gisonni, C. (2015). “Supercritical low-crested bilateral weirs: Hydraulics and design procedure.” Journal of Applied Water Engineering and Research, 3(1), 35–42.

Emiroglu, M, and Kaya, N. (2010). Discharge Coefficient for Trapezoidal Labyrinth Side Weir in Subcritical Flow. Water Resources Management, pp. 1-22. DOI:10.1007/s11269-010-9740-7.

Emiroglu, M. E., Kisi, O., and Bilhan, O. (2010). “Predicting discharge capacity of triangular labyrinth side weir located on a straight channel by using an adaptive neuro-fuzzy technique.” Advances in Engineering Software, 41(2), 154–160.

Emiroglu, M. E., Aydin, M. C., and Kaya, N. (2014). “Discharge characteristics of a trapezoidal labyrinth side weir with one and two cycles in subcritical flow.” J. Irrig. Drain. Eng., 140(5), 1–13.

Gonzalez, J., Rojas, H., Ortega, J., and Prieto, A. (2002). “A new clustering technique for function approximation.” IEEE Trans. Neural Netw., 13(1), 132–142.

Jalili, M. and Borghei, S. (1996). “Discussion: Discharge Coefficient of Rectangular Side Weirs.” J. Irrig. Drain Eng., 122(2), 132–132.

Nezami, F., Farsadizadeh, D., and Nekooie, M. A. (2015) “Discharge coefficient for trapezoidal side weir.” Alexandria Engineering Journal, 54(3), 595–605.

Parvaneh, A., and Borghei, S. M. (2009). “Oblique side weir.” Proc. 33rd IAHR-ASCE Congress, 9-14 August. University of British Columbia, Vancouver, Canada. Press, No.11310, pp. 1046-1053.

Parvaneh, A., Borghei, S. M., and Jalili, M. R. (2010). “Determination of discharge coefficient for oblique side weirs using the Partial Least Square method.” Proc. ISHPF 2010 Congress, 13-15 September. Nanjing Hydraulic Research Institute, Nanjing, China. Press, Volume 2, pp. 171-177.

Parvaneh, A., Borghei, S. M., and Jalili Ghazizadeh, M. R. (2011). “Discussion of discharge capacity of labyrinth side weir located on a straight channel.” Journal of Irrigation and Drainage Engineering, 137(11), 743–745.

Parvaneh, A., Borghei, S., and Jalili Ghazizadeh, M. R. (2012). “Hydraulic performance of asymmetric labyrinth side weirs located on a straight channel.” Journal of Irrigation and Drainage Engineering, 138(8), 766–772.

Parvaneh, A., Kabiri-Samani, A., and Nekooie, M. A. (2016). “Discharge coefficient of triangular and asymmetric labyrinth side weirs using the nonlinear PLS method.” J. Irrig. Drain. Eng., 10.1061/(ASCE)IR.1943-4774.0001081.

Parvaneh, A., Kabiri-Samani, A., and Parvaneh, M. (2017). “Discussion of prediction of discharge capacity over two-cycle labyrinth side weir using ANFIS” J. Irrig. Drain. Eng., 10.1061/(ASCE)IR.1943-4774.0001137.

Parvaneh, A., Yang, J., Javaheri, A., and Kabiri-Samani, A. R. (2016). “Discussion: Triangular labyrinth side weirs with one and two cycles” Proc. Inst. Civ. Eng. Water Manage., 10.1680/jwama.15.00032.

Prakash, M.N.S., Ananthayya, M.B., and Kovoor, G.M. (2011). Inclined Rectangular Weir-Flow Modeling. Earth Science India, Vol. 4, No. 2, pp. 57-67. DOI:10.1007/0974 – 8350(2011)4:2(57).

Ramamurthy, A. S., Qu, J., and Vo, D. (2006). “Nonlinear pls method for side weir flows.” J. Irrig. Drain. Eng., 132(5), 486–489.

Ura, M., Kita, Y., Akiyama, J., Moriyama, H., and Kumar, J. A. (2001). “Discharge coefficient of oblique side-weirs.” J. Hydrosci. Hydraul. Eng., 19(1), 85–96.

Uyumaz, A. (1992). “Side weir in triangular channel.” J. Irrig. Drain. Eng., 118(6), 965–970.

Vatankhah, A. R. (2013). “Water surface profile along a side weir in a parabolic channel.” Flow Meas. Instrum., 32, 90–95.