Journal of Biodiversity and Environmental Sciences (JBES)
ISSN: 2220-6663 (Print) 2222-3045 (Online)
Vol. 6, No. 1, p. 751-760, 2015
http://www.innspub.net

INNSPUB
RESEARCH PAPER

OPEN ACCESS

Experimental analysis of upstream channel slope effect on discharge coefficient in side weirs

Ali Hooshmand Aini[*], Habib Mousavi Jahromi, Hossein Sedghi, Amir Khosrojerdi

Department of Water Sciences and Engineering, Science and Research Branch, Islamic Azad University Tehran, Tehran, Iran

Article published on January 01, 2015

Key words: Side Weirs, Discharge coefficient, Experimental model, Upstream channel slope.

Abstract

Weirs are one of the oldest and simplest hydraulic structures which are used by hydraulic engineers for centuries in flow measurement, loss of energy, diversion of flow, water depth adjustment and other purposes. According to the popular usage of side weirs in irrigation and drainage system, discharge coefficient of side weirs obtaining, has always been considered by various water engineering researchers. In this research with the usage of experimental model, we have studied the effect of upstream channel slope on discharge coefficient in side weirs. According to the experimental results a non-dimensional equation for discharge coefficient calculation has been offered. At the end based on available equations we did statistical analysis of results. The reason of this event can be described in proximity of model assumption of the two examinations. As it is mentioned *Ranga* Raju *et al.* have done discharge coefficients on the wide edge weirs, Cheong has done discharge coefficients in Trapezoidal channels and Subramanya and Awasthy have done their studies on side weirs with zero threshold.

[*]**Corresponding Author:** Ali Hooshmand Aini ✉ ali_hooshmand1983@yahoo.com

Introduction

Weirs are one of the oldest and simplest hydraulic structures which are used by hydraulic engineers for centuries in flow measurement, loss of energy, diversion of flow, water depth adjustment and other purposes (Borghei *et al.*, 1999). The hydraulic design of a side weir is complicated because the flow conditions vary with distance along the weir and do not conform to simple weir theory. Two fundamental features common to all side weirs are:

-Flow over the weir starts when the water level in the parent channel reaches the crest level of the weir-for water levels less than this trigger level or first spill level, no water is diverted and all flow continues down the parent channel.

-The rate of flow diversion increases with increasing water level in the parent channel.

These fundamentals are illustrated in Fig. 1. (b) no flow over the weir, (c) initiation of spill, (d) weir spilling, and (e) maximum diversion.

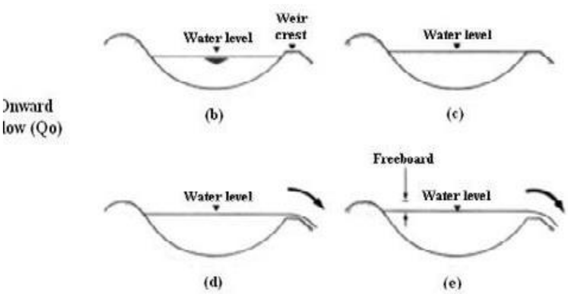

Fig. 1. Side weir, fundamentals: (a) schematic plan: and schematic sections showing.

In rivers, side weirs are commonly used to divert flood into temporary off-stream storage, or into a diversion channel. There may be a control structure on the main channel downstream of the side weir, in order to regulate flows into the downstream reach as a flood alleviation measure.

Flow in side weirs is a kind of spatial varied flows. A spatial varied flow is a permanent gradual varied flow which changes the varied discharge in the channel and varies along the amount of flow direction. According to the discharge variations, this type of flows is in divided in two groups: Spatial varied flows with increased of flow and Spatial varied flows with decreased of flow.

The design objective will be determined by the strategy for flood control. If the onward flow passes through an area of particular sensitivity to flooding, then an absolute limit on the onward flow may be required, If the side weir discharges into a bypass channel, and the capacity of the bypass is limited, then it may be appropriate for the side weir to take an increasing proportion of the total flow, with extreme floods being shared between the two streams. Often, the designer will have to compromise between having a long side weir that can discharge its design flow with very little head, and providing a shorter weir and a lower crest, with consequent early spills into a flood storage area or bypass channel. However, it should be noted that early spills into a flood storage reservoir could reduce its capacity to store the design flood, so careful consideration of the operation of the side weir is vital in developing the design.

Fig. 2. Side weirs in channel.

The side weir can vary from a simple lowered section of unreinforced flood embankment spilling into a seasonally flooded meadow; to a sophisticated concrete structure with a stilling basin discharging into a diversion channel (see Fig. 2) (Robinson and Mcghee, 1993). The aim of this research is the usage of experimental model and have studied the effect of upstream channel slope on discharge coefficient in side weirs.

Material and methods

Flow Characteristics of Side Weirs

Flow in side weirs is a kind of spatial varied flows. A spatial varied flow is a permanent gradual varied flow which changes the varied discharge in the channel and varies along the amount of flow direction. According to the discharge variations, this type of flows is in divided in two groups:

1) Spatial varied flows with increased of flow.
2) Spatial varied flows with decreased of flow.

The dynamic equation of spatial varied flows with increased discharge achieved by the relation below:

$$\frac{dy}{dx} = \frac{S_o - S_f - \left(\frac{2\beta Q}{gA^2}\right)q^*}{\frac{1-\beta Q^2 T}{gA^3}} = \frac{S_o - S_f}{1} \quad (1)$$

Side weirs are usually small hydraulic structures in which the length of the weirs rating to the width is less than 3. Di Marchi in (1934) could provide the hypothesis of rectangular and prismatic channel and the relation So-Sf=0 and α=1, in the direction of side weirs for the first time:

$$\frac{dy}{dx} = \frac{\frac{Q}{gB^2y^2}\left(-\frac{dQ}{dx}\right)}{1-\frac{Q^2}{gy^3B^2}} = \frac{Qy\left(-\frac{dQ}{dx}\right)}{gB^2y^3 - Q^2} \quad (2)$$

On the other side discharge on the weir and in unit of its length equals to:

$$-\frac{dQ}{dx} = \frac{2}{3} C_M \sqrt{2g}(y - \quad (3)$$

Which in it C_M modules id intensity of flow, and is known Di Marchi's modules. By assuming that specific energy is fixed, the amount of flow intensity in each channel is achieved through the phrase below:

$$Q = By\sqrt{2g} \quad (4)$$

With the combination of above relation and then integrating from two sides of the relation below which is known Di Marchi's module, the module is achieved.

$$x = \frac{3B}{2C_M}\left(\frac{2E-3W}{E-W}\sqrt{\frac{E-y}{y-W}} - 3\sin^{-1}\sqrt{\frac{E-y}{E-W}}\right. \quad (5)$$

In this relation X is the length of the side weir, B is the width of channel, E is specific energy, W is the height of weir and Y is the depth of flow (Aghazadegan, 2009).

The characteristics of the experimental model for studying

The experimental model for studying in earth channel includes in the length 32m, width of channel 1m with longitudinal slope of 0.001 and 0.003, with trapezoidal section. The length of weir is 4 m and the width is 0.8 m. Laboratory equipment includes pumps and generator, bathometer, theodolite. The slope of side weir considered zero and then the fluctuation of the water level measured with using bathometer. For calculating manning coefficient with obtaining d50 from aggregation curve and then using Strickler formula:

$$n = \frac{d_{50}^{1/6}}{21.1} = 0.0207 \quad (7)$$

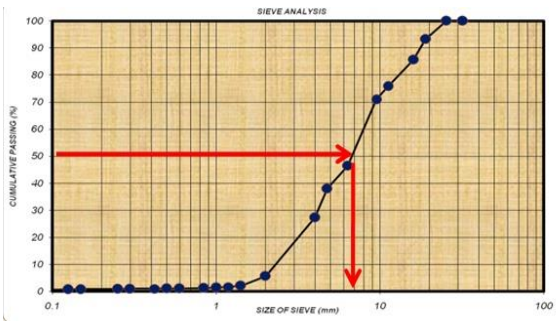

Fig. 3. Determine d50 using the aggregation curve.

In this article we use 3 bathometer for obtaining depth in upstream and downstream of channel and profile of water in side weir. For obtaining discharge we use rating curve. Schematic drawing of the model and the images of the model are shown in Fig. 4 and 5 (Nemaie *et al.*, 2013).

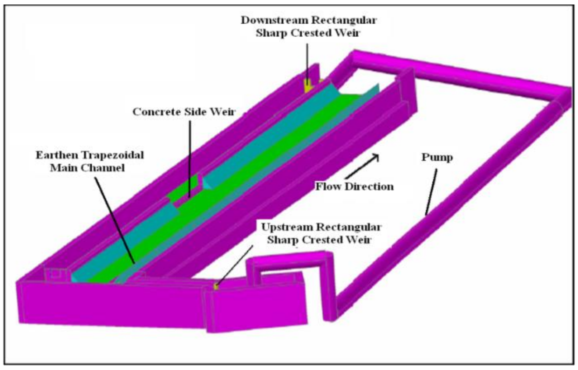

Fig. 4. Laboratory Setup (Nemaie *et al. 2013*).

Fig. 5. Images from the side weir and channel of the studied.

Results and discussions

Reviewing Previous Studies

From the beginning of the previous century until now, the behavior of flow in side weirs has caught a lot of attention to itself and many studies which are experimental characteristics have been done, Di Marchi achieved for the first time in (1934) that the dynamic equation of spatial varied flows by decreasing discharge with the assumption that the equation energy dominant on flow is fixed, and to calculate the output discharge from the side weir of intensity of flows module which is named the Di Marchi coefficient (Computers *et al.*, 2003). Since lake of accurate information about the Di Marchi's coefficient, this module is not trusted to use. Subramanya and Awasthy (1972) showed no interest in general equation differential of spatial varied flow with decreased Debi in a horizontal rectangular channel in which it has side weir with the height aero or limited and by doing examinations for the below and above critical flow, they provided relations to calculate the discharge's module for the side weirs with sharp edge (Hosseini and Abrishmi, 2002. Utech 1972) after studding the works of Subramanya and Awasthy stated that the equation provided by the mentioned people has errors in height of the weir (w>0) and the Froude number (Fr_1 > 0.6) and it offered a relation to identify the module of intensive flow in the rectangular side weirs.

Thomson and Nadsamorty (1972) by doing a survey of intensive flows module done by Subramanya and Awasthy provided relation for calculating the module of flow discharging. Ranga Raju *et al.* (1972) in the hydraulic lab of Roorkee University in India had been studied to verify the Di Marchi's module at first to estimate whether it can discharge from the sharp edge and wide edge. Finally it resulted the relations for calculating the rate of discharge for each of the mentioned weirs (Subramanya and Awasthy, 1972).

Hager (1987) by stating that the assumption of discharge's relation on normal weir is entrusted in side weirs offers a new formula for the side weirs. He stated that the module of intensive flow depends on the factors of speed rate to depth of flow, the angle of output flow and the shape of the channel (Hager, 1987). (Cheong 1991). Concentrated his studies on the rectangular side weirs in the trapezoidal channels and he also provided a relation to calculate the module of discharging in this situation (Cheong, 1991). Sing *et al.* (1994) indicated that though the intensity of flows module has the Froude number of high position rating to the height of the weir and by using multiple regression they achieved a relation to calculate the module of discharging (Singh *et al.*, 1994). In swami *et al.* studies (1994) a new concept named the positional module of intensive of flow became the field of interest and to calculate the intensity of flows module in the sharp-edge weirs without partition in two sides of the channel they provided a relation (Swamee, 1994).

Shafayee Bajestan and Izadjoo (1995) after presenting a computerized model to calculate the profile of water level along the side weir they offered a relation to calculate the module of flow discharging in the rectangular weirs with sharp edge (Shafayee Bajestan and Izadjo, 1995). In Jalili Ghazizade *et al.* (1996) the effect of various parameters on the module of discharging was rarified (Jalili Ghazizadeh *et al.*, 1996). They showed that in supercritical flow's the assumption that the specific energy in fixed in the length of the weir is not correct. Borghei and Salehi Neyshabori (2002) by considering the depth of the weir as the critical depth of side weir's Devi provided a relation to calculate the module of discharging. Hussein Mohammad ValiSamani (2004) studied the one-dimensional mathematical model for hydraulic side weirs in hydraulic jumping condition (ValiSamani, 2004). Uyumaz (2005) studied the side weir in triangular channels and provided a limited numerical model based on the assumption that the energy in the below critical and above critical of flow is fixed and also presented a profile for the water level (Uyumaz and Muslu, 1985).

Aghayari *et al.* verified the effect of height and width of top of the rectangular lateral prismatic rectangular channel (Honar, 2002). Bozargian and Yazdandoost studied the profile of water level on the side weir in a channel with a non-prismatic geometry and trapezoidal level. In Table 1 some of the most important relation for calculating the module of side weir's discharging is mentioned with the name of the researchers.

Table 1. The proposed equations for calculating the side weir discharge coefficient.

Row	Name a researcher (Year)	Conside-rations	The equation for determining discharge coefficient
1	Subramanya and Awasthy (1972)	$0 \le W \le 0.6$	$C_d = 0.864\sqrt{\frac{1-Fr_1^2}{2+Fr_1^2}}$
2	Utech (1972)	$0 \le W \le 0.6$	$C_d = 0.622 - 0.222Fr_1^2$
3	Thomson and Nadsamorty (1972)	$0 \le W \le 0.6$	$C_d = 0.864\sqrt{\frac{1-Fr_1^2}{2+Fr_1^2}}$
4	Ranga Raju *et al.* (1972)	$0.2 \le W \le 0.5$	$C_d = 0.81 - 0.6Fr_1$
5	Hager (1987)	W=0	$C_d = 0.485\left(\frac{2+Fr_1^2}{2+3Fr_1^2}\right)^{0.5}$
6	Cheong (1991)	W=0	$C_d = 0.45 - 0.22Fr_1^2$
7	Sing *et al.* (1994)		$C_d = 0.33 - 0.018Fr_1 + 0.49\frac{W}{Y_1}$
8	Swami *et al.* (1994)		$C_d = 0.447\left(\left(\frac{44.7W}{49W+Y}\right)^{6.67} + \left(\frac{Y-W}{Y}\right)^{6.67}\right)^{-0.15}$
9	Shafayee Bajestan and Izadjoo (1995)		$C_d = -0.0759Fr_1^2 - 0.7364\frac{W}{Y_1} - 0.0187\frac{L}{Y_1} + 0.199$
10	Ghodsian (1996)		$C_d = \left(0.611 + 0.075\left(\frac{Y-W}{W}\right)\right)(1 - 0.63Fr_1^{0.33})$
11	Jalili Ghazizade *et al.* (1996)		$C_d = 0.71 - 0.41Fr_1 - 0.22(\frac{W}{Y_1})$
12	Borghei and Salehi Neyshabori (2002)		$C_d = 0.82 - 0.38Fr_1 - 0.22\left(\frac{W}{Y_1}\right) + 0.08\left(\frac{L}{B}\right)$

The offered relations to calculate the module of side weir's discharge in the above table. W= the height of the top edge, L= the length of the weir, B= the width of the channel, Fr_1= the Froude number of flow before the weir and Y= the depth of water in every spot of channel.

After calculating the depth of channel in the section before side weir, the related parameters to the flow and also the discharge coefficient of flow has been calculated by available equations which has been shown in Table 2 and Fig. 6 to 9. In addition the obtained result was compared with other researchers' equations in Table 2.

Table 2. Results from the experimental model.

S	Y(m)	A (m2)	Q in (m3/s)	Q out (m3/s)	V(m2/s)	Fr1	Cm
0.001	0.072	0.082368	0.042	0.019	0.50990676	0.606846116	0.403236102
0.001	0.073	0.083658	0.05	0.024	0.597671472	0.706407257	0.446497853
0.001	0.075	0.08625	0.058	0.0263	0.672463768	0.784137662	0.522754384
0.001	0.088	0.103488	0.061	0.032	0.589440322	0.634530585	0.376274083
0.001	0.093	0.110298	0.069	0.039	0.62557798	0.655079539	0.358283781
0.001	0.1	0.12	0.074	0.034	0.616666667	0.622736798	0.428440293
0.003	0.058	0.064728	0.042	0.0245	0.648869114	0.86039358	0.424352119
0.003	0.06	0.0672	0.049	0.0259	0.729166667	0.950616257	0.532372264
0.003	0.076	0.087552	0.059	0.033	0.673885234	0.780608363	0.420323117
0.003	0.083	0.096778	0.065	0.036	0.671640249	0.744477751	0.410781783
0.003	0.093	0.110298	0.0695	0.042	0.630111153	0.659826492	0.328426799
0.003	0.106	0.128472	0.0965	0.0625	0.751136434	0.736749672	0.333695566

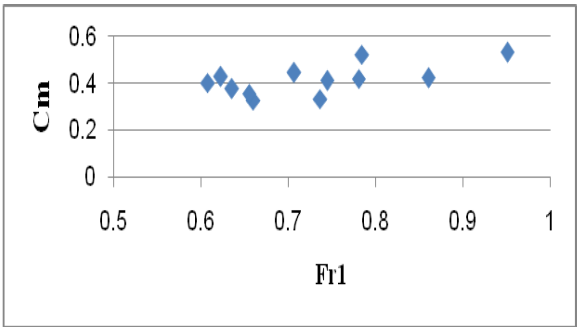

Fig. 6. Cm Values obtained from experimental result for different values of the Froude number.

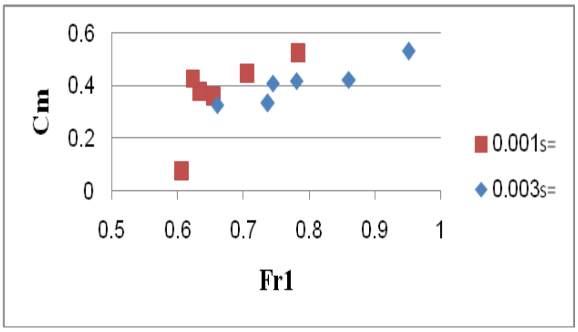

Fig. 8. Compare Cm values, obtained in 0.001 and 0.003 slopes for different values of Fr1.

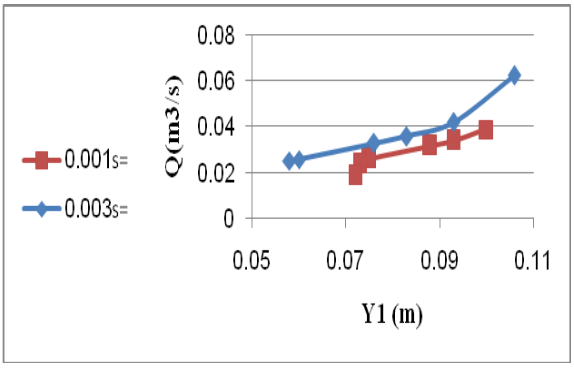

Fig. 7. Compare outlet discharge in different slopes.

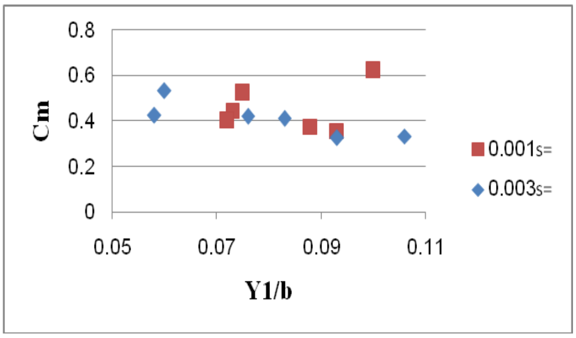

Fig. 9. Compare Cm values, obtained in 0.001 and 0.003 slopes for different values of Y1/b.

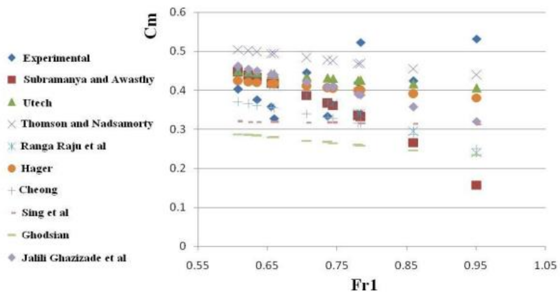

Fig. 10. Compare Cm of present results and the results of other researchers.

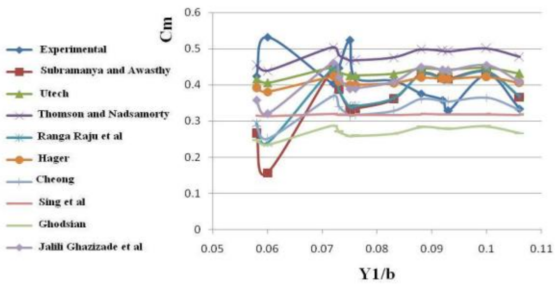

Fig. 11. Compare Cm of present results and the results of other researchers.

Extracting Equation to Determine the Side Weir Discharge Coefficient

In the flow over the side weir discussion, the relation between variations is defined according to the mentioned topics and Di Marchi equation (1968) like the function shown below:

$$C_m = f_1(V_1, Y_1, g, s, b, L, z, \mu, \sigma, \rho, Q_1) \qquad (8)$$

In above equation V1, Y1 and Q1 are orderly speed, depth and discharge in early section of the weir, L is the length of the weir, S is the slope of the main channel, b is the width of the weir and ρ, μ and σ are the constant coefficients. After making sure that the flow in the length of side weir is turbulent we can ignore the effect of the Reynolds number. Furthermore because during the examination the minimum height of water on the weir is always bigger than 5 mm, the effect of Weber number is negligible. After doing the calculation related to the dimensional analysis, discharge coefficient is a function of the dimensionless variations below:

$$C_m = f_2\left(Fr_1, \frac{Y1}{b}, S\right) \qquad (9)$$

As it is clear in the equation 9, the discharge coefficient of side weir is a function of Froude number of flow in the upstream of weir (Fr1), the ratio of depth of the flow in the upstream weir with the width of the main channel (Y1/b) and S is the slope of upstream main channel. As it is mentioned by the help of dimensional analysis and the overall shape of the relationship which is provided by the various researchers for the discharge coefficient of the rectangular sharp edge side weirs, the overall relation shown below is suggested to estimate the Side weir discharge coefficient:

$$C_m = aFr_1^{\,b} + c\left(\frac{Y1}{b}\right)^d + eS^f + h \qquad (10)$$

That in the above equation a, b, c, d, e, f, h are constant Coefficients and achieved by the help of the examinational data of this research. For this purpose, after a long trial and error and using the various forms of functions in the SPSS software we obtained the coefficients of the recent equation. SPSS software is operational software with the ability of estimating the function between two or several variations and predefined functions and statistical models and Stochastic. Furthermore in this software the model is analyzed by using the nonlinear regression method. This type of regression is a method to find a nonlinear model for finding the relation between dependent variable and a complex of independent variable. Unlike the traditional linear regression method that (limited the calculation of linear model) the nonlinear regression can voluntarily asses and measure the model relations between dependent variables and independent variables. Using that is completed according to estimation and assessment (Nemaie, 2013).

In the end the relation in which is brought in the continuation is obtained for estimation of the discharge coefficient of the side weirs, and the provided relations, are the most accurate relations among the relations extracted with the most trial and error examinations about the current character:

$$C_m = 0.445(Fr_1)^{1.6196} + 0.1793\left(\frac{Y1}{b}\right)^{-0.1515} + 0.0884(S)^{-0.2231} - 0.4849 \qquad (11)$$

To access the accuracy of the suggested relation above and its verification we have examined the comparison of discharge coefficient observations (obtained from examination) and calculations (obtained from the above equation). The obtained results are brought from the two methods in Table 3 and Fig. 12.

Table 3. Cm values obtained from equation 11 and experimental result.

Cm (experimental)	Cm (obtained from equation 11)	Percent error
0.403236102	0.39319283	-2.490668
0.446497853	0.447915486	0.3175006
0.522754384	0.493513512	-5.593619
0.376274083	0.400042102	6.3166769
0.358283781	0.409166087	14.201677
0.428440293	0.388696792	-9.276221
0.424352119	0.463000198	9.1075493
0.532372264	0.522726972	-1.811757
0.420323117	0.40101926	-4.582474
0.410781783	0.375535756	-8.580234
0.328426799	0.322069828	-1.93582
0.333695566	0.361401456	8.3739

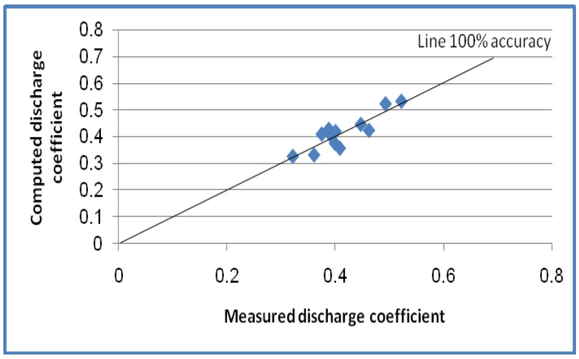

Fig. 12. Compare Observations discharge coefficient (Obtained from experiments) and Computed discharge coefficient (Obtained with equation 11).

Statistical Evaluation of the Results of the Discharge Coefficient of Side Weir

After extracting the proper relationship we will do statistical analysis of discharge coefficient results. To assess the accuracy of computational results of proposed equation we use statistical parameters. In this formula Cm is observational discharge coefficient, Cc is calculated discharge coefficient and N is the number of data.

A) Mean Absolute Percentage Error

The mean absolute percentage error (MAPE), also known as mean absolute percentage deviation (MAPD), is a measure of accuracy of a method for constructing fitted time series values in statistics, specifically in trend estimation. It usually expresses accuracy as a percentage, and is defined by the formula:

$$MAPE = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{e_i}{Q_w}\right| \times 100 \qquad (12)$$

Where e_i is the difference between experimental and computational values. Q_w is the actual value. According to the above equation this value for discharge coefficient of weir is obtained 6.0383.

B) Mean Error

The Mean Error is defined as follows:

$$ME = \frac{1}{N}\sum_{i=1}^{N}[C_m - C_c] \qquad (13)$$

According to the above equation this value for discharge coefficient of weir is obtained 0.013.

C) *Root Mean Square Error*

The root mean square error is defined as follows:

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}[C_m - C_c]^2} \qquad (14)$$

According to the above equation this value for discharge coefficient of weir is obtained 0.00225.

D) Statistical parameters α and R^2

This parameter represents the slope of the regression line and coefficient of determination and drawn based on regression line. Their values are respectively 1.001 and 0.878.

E) Mean Absolute Error

In statistics, the mean absolute error (MAE) is a quantity used to measure how close forecasts or predictions are to the eventual outcomes. The mean absolute error is given by:

$$MAE = \frac{1}{N}\sum_{i=1}^{N}|C_m - C_c| \qquad (15)$$

According to the above equation this value for discharge coefficient of weir is obtained 0.0243.

Conclusion

In this study the effect of upstream channel slope on the discharge coefficient of flow in side weirs had been examined. For this purpose the main channel with the slopes of 0.001 and 0.003 was examined. As it is shown in Fig. 7, with increasing flow coefficient, the depth of the flow increases in weir entrance and with increasing slope in the main channel we will observe that the depth of water decreases in weir entrance. According to Fig. 6, discharge coefficient of flow is almost constant in upstream with changes of the Froude number and didn't change dramatically. Furthermore according to Table 2 and Fig. 8 for a constant flow rate with increasing channel slope, discharge coefficient increases. By comparing Cm coefficients the research results are ready and the results of other researchers as we observe in Fig. 10 and 11 there is most proximity in the methods of Ranga Raju *et al.* and Cheong and Subramanya and Awasthy. The reason of this event can be described in proximity of model assumption of the two examinations. As it is mentioned Ranga Raju *et al.* have done discharge coefficients on the wide edge weirs, Cheong has done discharge coefficients in Trapezoidal channels and Subramanya and Awasthy have done their studies on side weirs with zero threshold. According to Table 3 and Fig. 12 we observe the appropriate likeness of obtained discharge coefficient from the equation 11 and the examinational discharge coefficient. In addition the statistical parameters for the obtained data from the equation 12 are achieved as, values of mean absolute percentage error, average error, root mean square error, the mean absolute error and statistical parameters α and R^2 in order 6.0383, 0.013, 0.00225, 0.0243, 1.001, 0.878 .As it is observed the suggested relation almost has a good accurately estimation.

References

Aghazadegan A. 2009. Numerical and Experimental Investigation of Flow in Side Weir of Dam (case study: side weir of Ajabshir dam), Ms.c dissertation, Islamic azad university of science and research, Tehran branch 22-24.

Borghei SM, Jalili MR, Ghodsian M. 1999. Discharge coefficient for sharp crested side weir in subcritical flow, J of Hydraulic Engineering **125 (10).**

Cheong HF. 1991. Discharge coefficient of lateral diversion from trapezoidal channel, J. Irrig. Drain. Eng **117(4),** 461–475.

Computers RWO, May BC, Bromwich Y, Gasowski CE, Rickard. 2003. Hydraulic Design of Side Weirs, Thomas Telford Publishing 4-10.

Hager WH. 1987. Lateral outflow over side weirs, J. Hydraulic. Eng **113(4)**, 491–504.

Honar T. 2002. Hydraulic algorithm of inclined side weirs in non-prismatic channels.

Hosseini SM, Abrishami J. 2002. Hydraulic in open channel, Ferdosi Mashhad University Publication, 3th edition 355.

Jalili Ghazizadeh MR, Borghei M, Ghodsian M. 1996. Experimental investigation of side weir in subcritical flow, 4th International conference of civil engineering, Tehran.

Nemaie MR, Sabagh Yazdi SR, Jalalediny MS, Habibi M, Gafouri Azar M. 2013. Experimental Investigation on Discharge Coefficient of Side Weir in Floodwater Spreading Systems.

Robinson DI, Mcghee TJ. 1993. Computer modeling of side-flow weirs, J of Irrigation and Drainage Engineering **119 (2).**

Shafayee Bajestan M, Izadjo F. 1995. Computer modeling to design a side weir, Journal of Tabriz University.

Shahab J. 2004. Meet spss software for analyzing, Institute of Statistics 31.

Singh R, Manivannan D, Satyanarayana T. 1994. Discharge coefficient of rectangular side weirs. ASCE Journal of Irrigation and Drainage Engineering **120(4)**, 814-9.

Subramanya K, Awasthy SC. 1972. Spatially varied flow over side weirs, J. Hydr. Eng. ASCE **98(1)**, 1-10.

Swamee PK, Santosh KP, Masoud SA. 1994, Side weir analysis using elementary discharge coefficient." J. Irrig. Drain. Eng **120 (4)**, 742–755.

Uyumaz A, Muslu Y. 1985. Flow over side weir in circular channels." J. Hydraul. Eng **111 (1)**, 144–160.

ValiSamani HM. 2004. Dimensional mathematical model of a hydraulic jump hydraulic side weir in place, Journal of Agricultural Sciences and Natural Resources, Volume IV, Issue VI.