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Flow Over Side Weirs with Experimental & CFD Results

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***Abstract:** In irrigation, sewer systems and drainage engineering side weirs are used to as a hydraulic control structure from many decades. Labyrinth side weir is a side weir with increased crest length due to folding in plan view as it provides additional length for a given opening. As a flow diversion structure in irrigation, land drainage, urban sewage systems and in intake structures. Labyrinth side weirs can be used more efficiently than conventional side weirs. In this review paper some investigations of researchers with different parameter affecting coefficient of discharge and discharging capacity of side weirs are presented. In review it seems that different parameters are affecting on discharge of side weir has been considered in empirical equations given by researcher but few parameters are left for consideration. In this paper effect of additional parameters like side weir thickness and submergence condition is evaluated by CFD models which can be a research tool to investigate future scope.*

***Keyword:** Side weir, CFD, Labyrinth side weir, Coefficient of discharge.*

I. INTRODUCTION

A side weir is used for flow regulating device in irrigation, water distribution, waste-water engineering, drainage, flood control and other hydraulic structures. It is used to divert flow from main channel to side channel when water level raised above maximum allowable limit. The flow over a side weir is a typical case of spatially varied flow with decreasing discharge. The governing differential equation for such a flow is:

$$\frac{dy}{dx} = \frac{S_0 - S_f - \frac{Q}{gA^2}\frac{dQ}{dx}}{1 - \frac{Q^2 T}{gA^3}} \quad (1)$$

Discharge over side weir is proposed by De Marchi (1934)[1] which is used by several researchers. In De Marchi equation an elementary strip of discharge dQ of length ds along the side weir in rectangular main channel is considered, given as below.

$$-\frac{dQ}{ds} = \frac{2}{3} C_d \sqrt{2g}(h - p)^{3/2} \quad (2)$$

where Q=discharge in the main channel; dQ/ds or q= per unit length spilling discharge of the side weir; g=acceleration due to gravity; h=depth of flow measured from the channel bottom along the channel centerline; p=height of the side weir, s=distance from the beginning of the side weir;; and Cd =discharge coefficient of rectangular side weir.

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De Marchi (1934) equation was extensively used for coefficient of discharge for side weirs which includes different types of side weirs such as rectangular side weir, trapezoidal side weir, circular side, labyrinth side weirs etc. Researchers have used different parameters which depend upon the Cd. In this paper we have reviewed papers on different types of side weirs and discussed different parameters. Also some CFD model results are presented which required more detailed investigations of different parameters.

II. LITERATURE REVIEW SIDE WEIR

Side weir discharge coefficient equation was given by Subramanya et al. (1972)[2], Nandesamoorthy et al. (1972)[3], Yu-tech [(1972)[4], Ranga Raju et al. (1979)[5], Hager (1987)[6] and Cheong (1991)[7], etc. have given equations of coefficient of discharge which depends on Froude number as shown in Fig 1.Figure clearly shows that the equation given by all researchers does not verify the result of one another although in all cases Cd decreases with increase in Froude number.

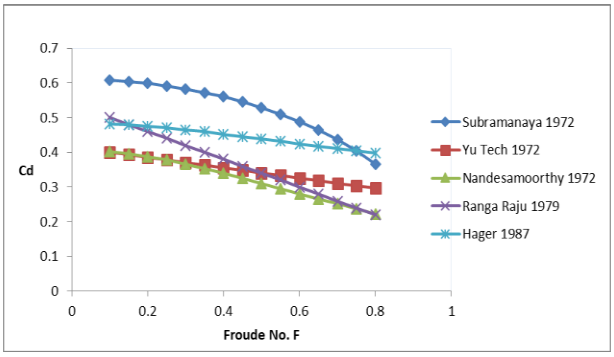

Fig 1. Cd versus Froude number by researchers

Singh et al. (1995)[8] had conducted experiments in a prismatic rectangular channel to determine the Froude number effect also analyzed the results of sill height variation on coefficient of discharge for range of Froude number of subcritical condition. The experimental setup was consisting of 23m long channel with 0.25m width and 0.35m depth. And side channel has 4m length with 0.25m width and 0.35m depth. Result shows that there was a rising trend of water surface profile along the length of crest of side weir. The experiments was for Cd range of 0.45 to 0.84 and it was observed that coefficient of discharge decreases with the increase in Froude number as shown in Fig.2. They had given a empirical equation for coefficient of discharge which depends on ratio of sill height to upstream flow depth and upstream Froude number.

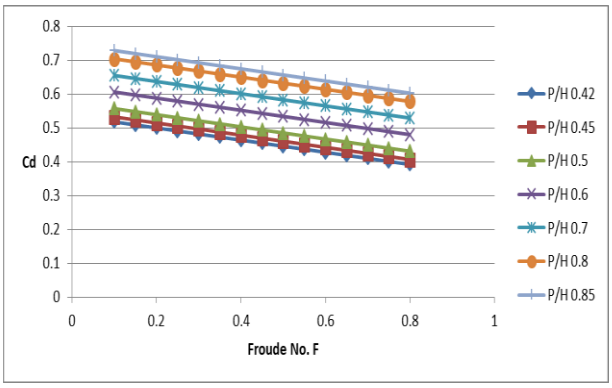

Fig. 2. *Cd* versus Froude number with different P/H values. (Singh et al. 1994)

Swamee et al. (1994) [9] explained the elementary side weir coefficient of discharge on the basis of numerical solution. He has solved the ordinary differential equations of flow depth and discharge. The variation of width of crest of triangular side weir has been investigated and equation of coefficient of discharge for broad crested and sharp crested weir has presented.

Bagheri. S. et al (2012) [10] has conducted experiments to investigate the hydraulic features of rectangular sharp crested side weirs. The experimental setup consists of 8m long rectangular flume having 0.4m width and 0.6m depth. Steel plate made weirs with 60^0 angle were fixed. Variation of parameters is shown in Fig.3 and Fig 4.

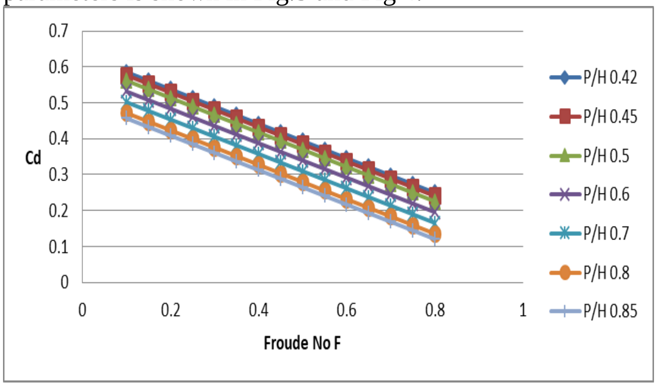

Fig. 3. *Cd* versus Froude number with different P/H values. For L/B =1 (Borghei et al. 2012)

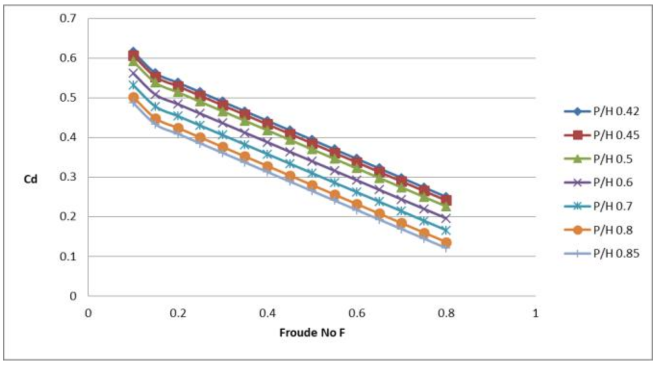

Fig. 4. Cd versus Froude number with different P/H values. For L/B =1.5 (Borghei et al. 2012)

Sharareh Mahmodinia et al (2014) [11] has conducted numerical simulations by using Volume of Fluid (VOF) scheme in CFD. Among various turbulence models they preferred Reynolds Stress Model (RSM) turbulence model to study free surface flow over a side weir. In geometry boundaries of solid wall, free surface and inlet, outlet has been defined considering nature. Uniform distributions were given for all of dependent variables with separate inlet for water and air. Pressure outlet conditions were defined in main channel and side channel from where fluid will exit the mesh. In simulations they found that water surface profile is quite similar in higher over flow condition of side weir and low overflow condition of normal weir. In comparison of maximum depth in downstream along the side weir section, water depth is reduced.

In experimentation under high over flow rate occurrence of separation zone was found at near to wall with decreasing height, and this separation zone moved to downstream end with increasing width of side weir.

Crest height and of side weir opening has varied to find the effect on discharge and hydraulic characteristics and comparison has been done. Doppler velocity meter has been used to measure Velocity variation and alteration in x, y and z component of velocity above the crest and vicinity of the side weir. At larger distance in both upstream and downstream form weir plan was horizontal and values of velocities in y and z directions are very small and x component of velocity is highest at the beginning of the weir and near the end it was lowest. The vertical velocity gradually decreases with increase of depth of flow. The analysis of 3D velocities shows that stagnation zone occurs close to the side weir end. At the side weirs end the hydraulic behavior is same as normal weir and evacuation can be increased.

Emiroglu et al. (2010) [12] investigated the hydraulic characteristics of triangular labyrinth side weirs. He attracted due to larger discharging capacity due to increased crest length for a fixed opening. The experimental setup consists of experimentation in a 12m long rectangular flume with 0.5m width and 0.5m depth with 0.001 bed slope. For controlling the discharge and height of water in downstream sluice gate is installed. The flow over labyrinth side weir was collected in separate side channel. In that experimentation they had studied coefficient of discharge, longitudinal velocities of triangular labyrinth side weir and water surface profile. They have tested labyrinth side weirs with included angle of 120^0, 90^0,450, $60^0$and linear side weir for different side weir openings.

The effect of ration of side weir opening and main channel width on coefficient of discharge for lesser labyrinth side weir included angles (45^0 and 60^0) is very significant. But, the effect for larger side weir included angles (120^0 and 150^0) is less than low labyrinth weir included angle. They found that discharge coefficient is directly proportional to Froude number as shown in Fig.5. They found that the coefficient of discharge for the labyrinth side weir is 1.5–4.5 times higher as compared with rectangular side weir. An equation for coefficient of discharge is also defined as given in equation 3. They concluded that the discharge coefficient increases when L/b ratio and p/b ratio variation in the labyrinth weir included angle causes a considerable increase in Cd due to increasing the overflow length.

$$Cd = [18.6-23.535\ (L/B)^{0.012} + 6.769\ (L/l)^{0.112} - 0.502\ (P/h)^{4.024} + 0.094 \sin\theta]^{-1.431} \quad (3)$$

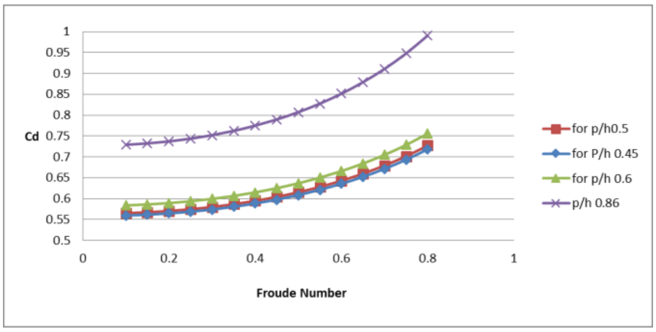

Fig. 5. *Cd* versus Froude number with different P/H values. For L/B =0.5, L/l = 0.5 (Emiroglu et al. (2010)

M. Cihan Aydin (2012)[13] investigated characteristics and hydraulic behavior of over the triangular labyrinth side weirs & surface profiles pattern has been analyzed in the subcritical flow condition, by using CFD simulations with Fluent code. Water surface profiles under subcritical condition were plotted computationally and compared with experimentally along the side-weir length and in the channel centerline, variation were reported in the water level along the side weir upstream and downstream. Initially at upstream water level decline and at downstream water level rises. Water level drop is due to effect of entrance of side weir opening. In sharp edge side weirs, a vortex or circular motion occurred in the triangular labyrinth which causes a drop of water level at the upstream of weir. Significant occurrence of surface jump was observed when Froude number is more than 0.3on downstream of minimum water level while the Froude number is increasing, with rise in surface elevation jump moves to the downstream of side weir.

III. EMPIRICAL EQUATIONS OF SIDE WEIRS

Many researchers have investigated the flow properties side weirs considering different parameters and developed empirical equations for determination of coefficient of discharges as given in Table No.I. It can be seen that most of the researcher considered only few parameters. But present study of few CFD simulation shows that additional parameters may increase the accuracy of equations presented

IV. METHODOLOGY, GEOMETRY AND BOUNDARY CONDITION

The geometry of the labyrinth side weir consists of a main channel 0.5m wide with depth of 0.5m. The side weir opening is provided at the center of this channel. Floor of the main channel is also modeled and it is 0.05m thick. 0.75m Side weir opening is provided with crest height of 0.12m for all the cases. Thickness of the side weir wall is kept at 0.03m. At the end of the channel there is an obstruction for raising the water level in the channel which is 0.2m tall and 0.1m thick. The bottom boundary in the channel is blocked by the channel bed but after the side weir there is an opening left which will expose the bottom boundary to the fluid and fluid can pass out of the domain through it. Uniform hexahedral fine mesh of 13mm is used.

Table: I Empirical equation given by researchers

Researchers	**Coefficient of discharge**	**Range of Froude Number**	**Type of channel/ Side weir**
Subramanya and Awasthy (1972)	$Cd = 0.864(1-F^2_1/2+F^2_1)^{0.5}$	0.02 to 0.85	
Yu-Tech (1972)	$Cd = 0.415-0.148F1$	--	
Nandesamoorthy and Thomson (1972)	$Cd = 0.288\ (2-F^2_1\ /1+2F^2_1)^{0.5}$	--	
Ranga Raju et al. (1979)	$Cd= 0.54-0.40F_1$	0.10 to 0.50	
Hager _1987_	$Cd= 0.485\ (2+F^2_1/2+3F^2_1)^{0.5}$	0.0 to 0.87	
Cheong (1991)	$Cd=0.30-0.14F^2_1$	0.28 to 0.78	for trapezoidal channel
Singh et al. (1994)	$Cd=0.33-0.18.F_1+0.49p/h$	0.23 to 0.43	
Borghei et al. (1999)	$Cd=0.7-0.48F1-0.3p/h1+0.06L/b$	0.1 to 0.9	
Ura et al. (2001)	Cd = 0.611 [cosθ(3F21/2+ F21)0.5 + Sinθ (1-(3F21/2 + F21))0.5] sinθ		Oblique side weir
Emiroglu et al (2010)	$Cd = [18.6-23.535\ (L/B)^{0.012} + 6.769\ (L/l)^{0.112} - 0.502\ (P/h)^{4.024} +0.094Sin\theta]^{-1.431}$	0.1 to 0.8	Single cycle labyrinth side weir

V. RESULT & DISCUSSION

A. Effect of Labyrinth weir thickness on Cd

From the research papers review it appears that the thickness of labyrinth side weir is not considered by the researchers to investigate coefficient of discharge. In this paper we are presenting the result of CFD simulation of labyrinth side weir as shown in Fig. 6 with different thickness of labyrinth side weirs. As shown in Table .II it is clear that thickness of labyrinth side weir also affect on discharge over labyrinth side weir. For 50mm thickness of labyrinth side weir the discharge is more as compare to 70mm and 80mm thickness of labyrinth side weirs.

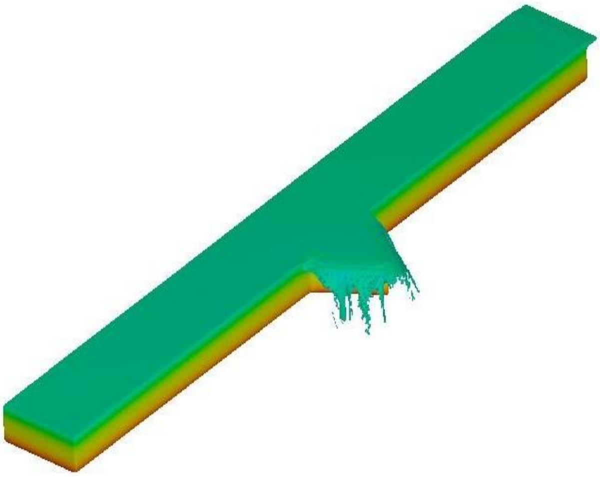

Fig No.6 Flow over a triangular Labyrinth 60

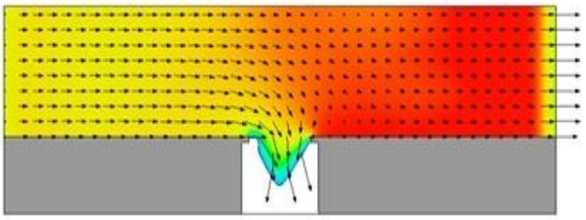

Fig 7. Velocity vector of streamlines

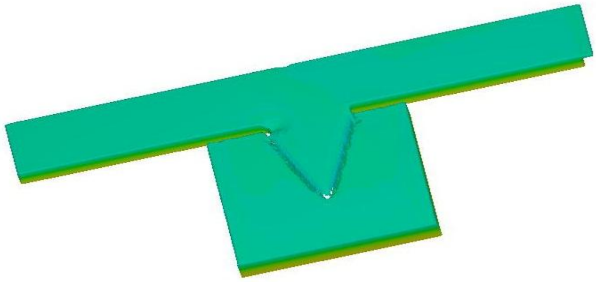

Fig 8. Flow over a submerged triangular Labyrinth 60

B. Effect of Downstream water of discharge of labyrinth side weir

Submergence of a side weir is a general case which arises due to increase of water depth due to less discharging capacity of side channel. If submergence arises then also discharge capacity of labyrinth side weir is affected as shown in table No. III. In submerged condition labyrinth weir discharging capacity is less as compare to without water in downstream. The velocity of stream line affected due to presence of water in downstream. The discharging capacity of water is depends on divergence of water streamline from main parent channel to labyrinth side weir as shown in Fig.7

Table No. II Effect of thickness of labyrinth side weir

Labyrinth	**Crest height**	**Head of water**	**Froude No.**	**Side weir opening L**	**Side weir thickness**	**Side weir discharge**
Triangular Labyrinth 60	150mm	2007 mm	0.024	500mm	50mm	0.02375 m^3
Triangular Labyrinth 60	150mm	2007 mm	0.024	500mm	50mm	0.0233 m^3
Triangular Labyrinth 60	150mm	2007 mm	0.024	500mm	50mm	0.02321 m^3

Table No. III Effect of submergence of labyrinth side weir

Labyrinth with condition	**Crest height**	**Head of water**	**Froude No.**	**Side weir opening L**	**Side weir thickness**	**Side weir discharge**
Triangular Labyrinth 60 (Without downstream water)	150mm	2007 mm	0.024	500mm	50mm	0.02375 m^3
Triangular Labyrinth 60 (submerged weir)	150mm	2007 mm	0.024	500mm	50mm	0.01890 m^3

VI. CONCLUSION

The conclusion can be listed as following which are based on investigations of researchers and CFD simulations done for few parameters.

a) Experimental results of many researcher shows that the variation in the coefficient of discharge for sharp crested rectangular side weir located on a rectangular main channel depends on many parameters and, the results of dimensional analysis indicate that the dimensionless parameters of L/b and L/h should be considered in equations which determines the discharge coefficient of the side weir.

b) Free surface flow over labyrinth side weir is simulated by using FLUENT program. Comparisons with the measurements show that the predictions of coefficient of discharge required with additional parameters. As thickness of labyrinth side weir also effect on discharge coefficient.

c) Effect of submergence also required to investigate because it affect coefficient of discharge. CFD simulation can be successfully used for investigation of different parameters.

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