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A Review of Investigations About Geometry Shape and Discharge Coefficient of Side Weirs

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Abstract

The side weir is a hydraulic structure constructed longitudinally on the side of the main channel and is mainly used to reduce the flood wave and irrigate the lands. This study provides an overview of the side weirs and investigations about the geometry shape and discharge coefficient of the side weirs. The discharge coefficient equations depend mainly on the Froude number. Some dimensionless variables are used to study the discharge coefficient in conjunction with the Froude number, such as ratio side weir height to the head water on crest and the opening side weir length to the crest width . On the other hand, the length of the crest is considered a determinant for the selection of the side weir, where the dams with a long crest such as W shape, labyrinth and piano key side weir allow the passage of discharge through them higher than rectangular side weirs with (1.5-7.5) times.

Keyword: *side weirs, discharge coefficient, geometry shape, hydraulic structure, side weirs overview*

I. Introduction

Rivers are one of the most important sources of life. The greatest civilizations were built around rivers because of their use of water in agriculture, drinking, irrigation of crops, industry and household chores. It is considered a suitable environment for the life of many organisms, such as animals and plants. It has recently been used to generate electric power and store water in dams to be used when needed and transported from one area to another. And the areas surrounding the rivers are considered the best lands for agriculture. On the other hand, rivers are also a threat to people and property. Risks arise from floods that occur due to rain or defects in human performance or in the design and construction of dams.

To reduce flood risks and to control and store water to benefit from it in the dry season, many studies and research have been conducted on the possibility of building water facilities on rivers such as dams, spillways, reservoirs, weirs, gates, barriers, canals, etc. One of the most important facilities built on the main river channels to

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reduce flood risks is the side weirs, also it is used to irrigate agricultural areas, control the water level in the main canal and divert water to branch canals (Bromwich, Rickard, Gasowski, & May, 2003).

A side weir is also a flow regulating structure which is constructed in the sidewall of the channel, which allows lateral flow when the liquid surface is above the crest of side weir. When the crest of side weir is not straight in the plane form, then side weir becomes labyrinth side weir (Emiroglu, Agaccioglu, & Kaya, 2011). Due to the increase in crest length on the plan, labyrinth side weirs could overflow more discharge when compared to classical side weirs. This increase in the effective length of the crest is achieved by folding the crest of side weir in various forms like triangular, trapezoidal and other shapes (Ansari & Patil, 2020).

The side weirs in this respect provides a viable alternative to mitigate flood risks. First, because the side weirs are free flowing dams, they reduce the risk of the gates not being opened during irrigation or flooding. Second, the side weirs has a higher drainage density and allows even to restore the global storage volume (Lempérière & Ouamane, 2003) and (Tiwari & Sharma, 2017) the side weirs has a higher drainage capacity, which can safely pass the excess flood water downstream at a lower level upstream compared to a gated dam when the reservoir is Below normal for severe floods (Lempérière & Vigny, 2011).

This study provides an overview of the side weirs and investigations about the geometry shape and discharge coefficient of the side weirs.

II. Overview of Side Weirs

Free-flow spillways are simpler and reduce the risk of not opening during high floods and hence safer than gated ones. The discharge through free fall spillways is dependent on the crest length research as such has been carried out extensively for increasing the crest length and design a spillway which comprises: (a) a shape which can be both, placed on an existing or be built entirely for a new dam, (b) a shape which is structurally simple but stable to construct with general engineering knowledge, (c) increased discharge intensity and (d) more cost-effective.

Side weirs have been studied and analyzed by many researchers such as (De Marchi, 1934), (ACKERS, COLEMAN, SMITH, & BERNOULLI, 1957), (Frazer, 1957), (Subramanya & Awasthy, 1972), (El-Khashab & Smith, 1976), (Uyumaz & Muslu, 1985), (Ranga Raju, Gupta, & Prasad, 1979), (Ramamurthy & Carballada, 1980), (Borghei, Jalili, & Ghodsian, 1999) and (Ghodsian, 2003). The diversity of studies on side weirs where the physical and numerical models were made to find suitable designs for the purpose that require. (Gabl et al., 2014)), (Khassaf, Attiyah, & Al-Yousify, 2016), (Hoseini, Jahromi, & Vahid, 2013), (Abdollahi, Kabiri-Samani, Asghari, Atoof, & Bagheri, 2017), (Aydin, 2012), (Aydin & Emiroglu, 2013) and (Aydin & Emiroglu, 2016) they studied the shape and engineering properties of the side weirs and its effect on increased drainage by computation fluid dynamic (CFD). On the other hand, (IKINCIOGULLARI & EMIROGLU, 2019), (Kisi, Emiroglu, Bilhan, & Guven, 2012), (Parsaie & Haghiabi, 2017), (Khalili & Honar, 2017), (Mamand & Raheem, 2018), (Emiroglu, Kaya, & Agaccioglu, 2010), (Kaya, Emiroglu, & Agaccioglu, 2011), (Dursun, Kaya, & Firat, 2012) and (Coşar & Agaccioglu, 2004) they used experimental laboratory test to study of engineering properties.

From applications of the side weir, Electricité de France built the first PKSW in 2006 at the Goulours dam in France (Laugier, 2007) and project has been carried out in the Swarakuddu project in India. based on field experience in different countries, has been accounted for by various authors (e.g., Switzerland (Laugier, Pralong, & Blancher, 2011), (Eichenberger, 2013), Vietnamese PKW (Hien, Son, & Khanh, 2006), (Khanh, Hien, & Hai, 2011), in Sri Lanka (H Jayatillake & Perera, 2013), (HM Jayatillake & Perera, 2017), in Iran (Javaheri & Kabiri-Samani, 2012), French (Laugier, Lochu, Gille, Leite Ribeiro, & Boillat, 2009), and India (Da Singhal & Sharma, 2011). Others are described in Belgium (Erpicum, Machiels, Dewals, Pirotton, & Archambeau, 2012) and in the USA (Anderson & Tullis, 2011).

Geometric Shape

There are many types of side weirs that differ according to the available data, such as the topography of the area, channel type, flow velocity, peak length, crest type and cost. So it is possible to find many types that differ in terms of geometry shape, such as circular, trapezoid, triangle, rectangular, curved and zigzag etc. In most cases, the side weirs is designed to avoid flood risks, as the design depends on the velocity of transferring or shifting the flood wave from the main channel to the secondary channel. As such, the amount of water produced by the flood wave, the width of the channel, and the area topography are the primary determinants in choosing the shape of side weirs (Abhash & Pandey, 2020). Figure 1 shows some shapes of the side weirs.

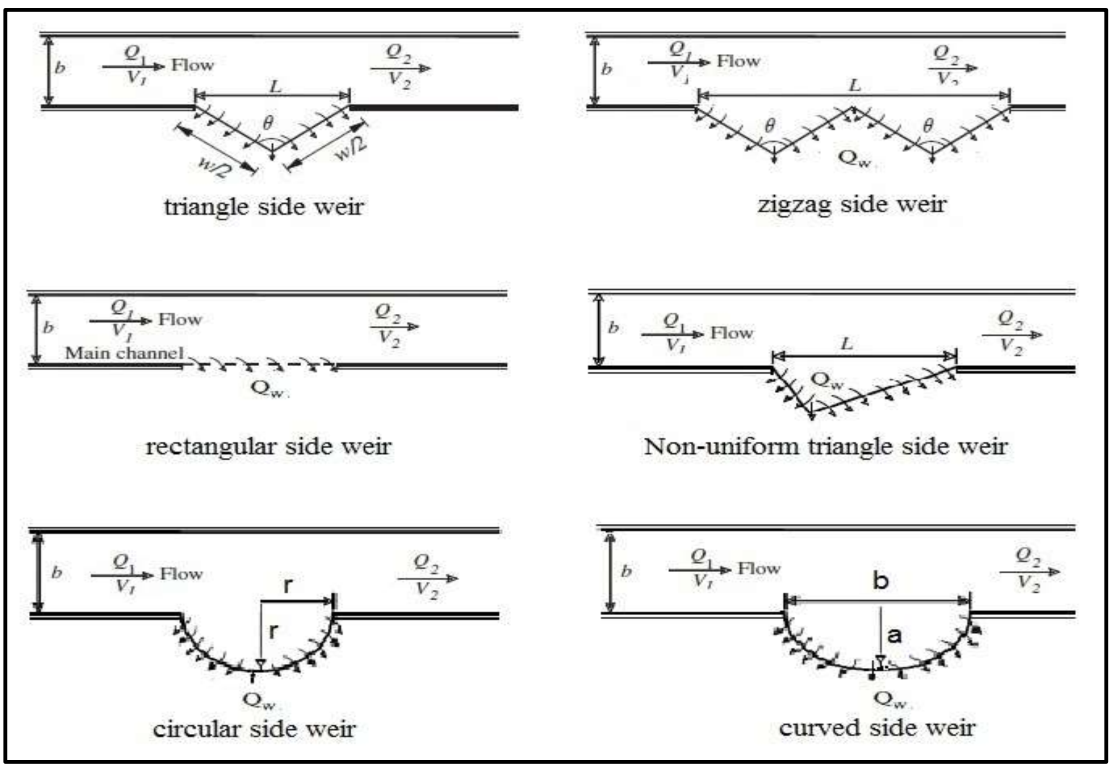

Figure 1: some shapes of the side weirs.

Recently, many side weirs have been developed such as piano key and labyrinth side weir, It can give high drainage efficiency with less water head over the weir for narrow and wide channels (Abhash & Pandey, 2020), (Pralong et al., 2011), (Pinchard, Boutet, & Cicero, 2011), (Phillips & Lesleighter, 2013), (Botha, Fitz, Moore, Mulder, & Van Deventer, 2013) and (Valley & Blancher, 2017). The piano key and labyrinth side weir has proven its superiority over the other types of weirs such as triangle, rectangular and curve etc., (Le Blanc, Spinazzola, & Kocahan, 2011), (Mohammed, Al-Dulaimi, & Alfatlawi, 2019) and (Ouamane, Debabeche, Lempérière, & Vigny, 2017).

Discharge Control Capacity

Free surface flow are affected by the value of Froude number, if this value is changed gradually then the phenomenon is called spatially varied flow (SVF). Side weir is a hydraulic structure used for diverting flow from the main channel into the side channel whenever the water surface rises above the side weir crest, and the flow overflows over it freely under gravity. Their hydraulic behavior is complex and exhibition to change due to different free surface profiles along the side weir. (De Marchi, 1934) is one of the earliest investigators who gave equations for the flow over side weirs on the basis of a constant specific energy along this structure. The governing differential equation for such a flow is:

$$\frac{dy}{dx} = \frac{S_o - S_f - \frac{Q}{gA^2}\frac{dQ}{dx}}{1 - \frac{Q^2 T}{gA^3}} \tag{1}$$

Where: y is the depth of flow, x is the distance along the side weir from upstream end, So is the main channel slope, Sf is friction slope, α is kinetic energy correction factor, Q is discharge in channel, dQ/dx is discharge per unit length of side weir, g is the acceleration due to gravity, A is the cross sectional area of flow and T is the top width of the channel section.

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

Where: dQ/ds or q= per unit length spilling discharge of the side weir; 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 C_d =discharge coefficient of rectangular side weir.

(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. Side weir discharge coefficient equation was given by (Subramanya & Awasthy, 1972), (Nandesamoorthy & Thomson, 1972), (Yu-Tech, 1972), (Ranga Raju et al., 1979), (Bremen & Hager, 1989) and (Cheong, 1991), etc. have given equations of coefficient of discharge which depends on Froude number as shown in Figure 2. 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.

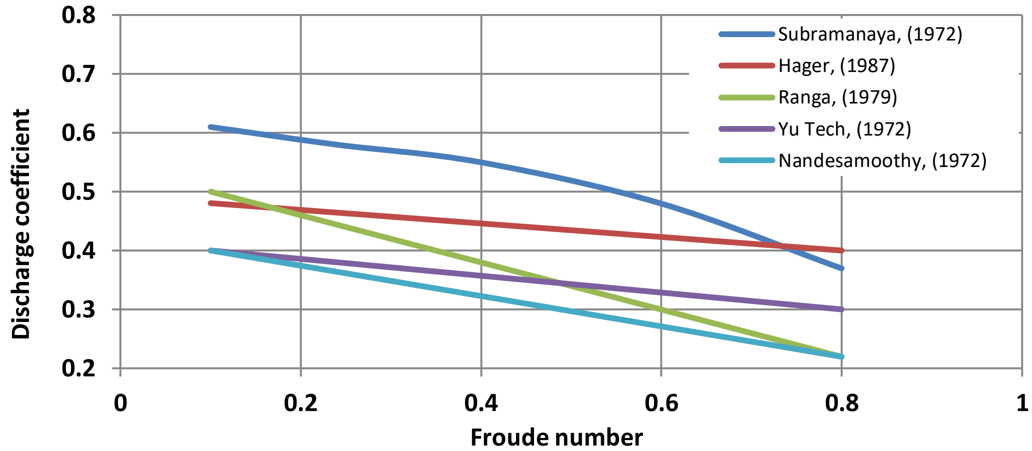

Figure 2: Discharge coefficient against Froude number by researchers

(Singh, Manivannan, & Satyanarayana, 1994) 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 Figure 3. 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.

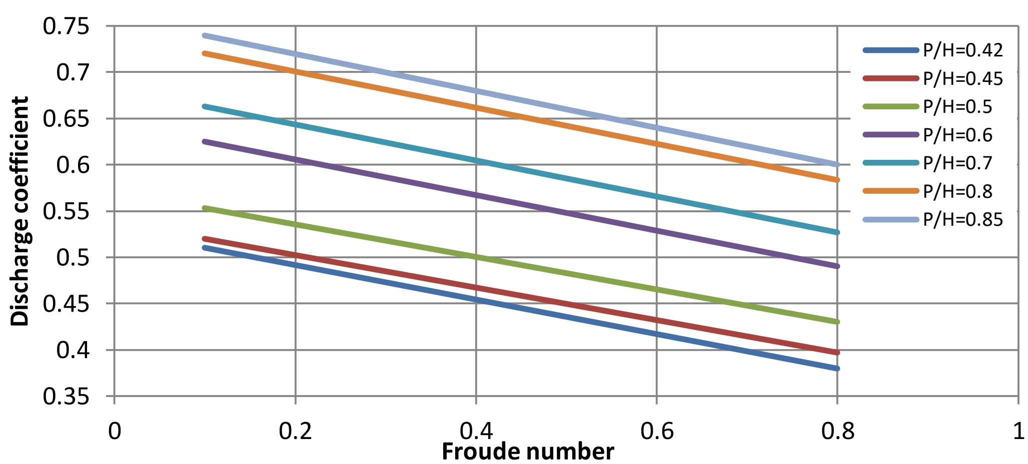

Figure 3: Discharge coefficient against Froude number with different P/H values. (Singh et al., 1994).

(Swamee, Pathak, & Ali, 1994) 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 & Heidarpour, 2012) 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 600 angle were fixed. Variation of parameters is shown in Figure 4 and Figure 5.

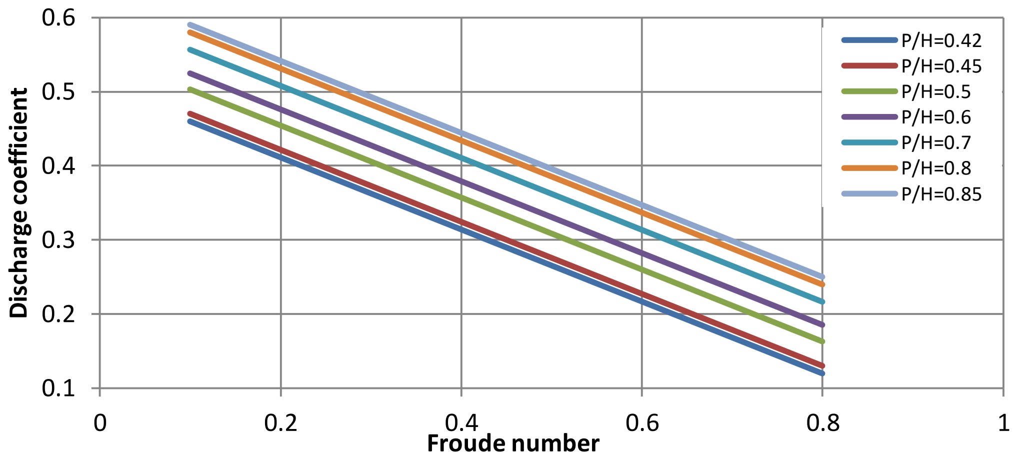

Figure 4: Discharge coefficient against Froude number with different P/H values. For L/B =1 (Borghei et al., 1999).

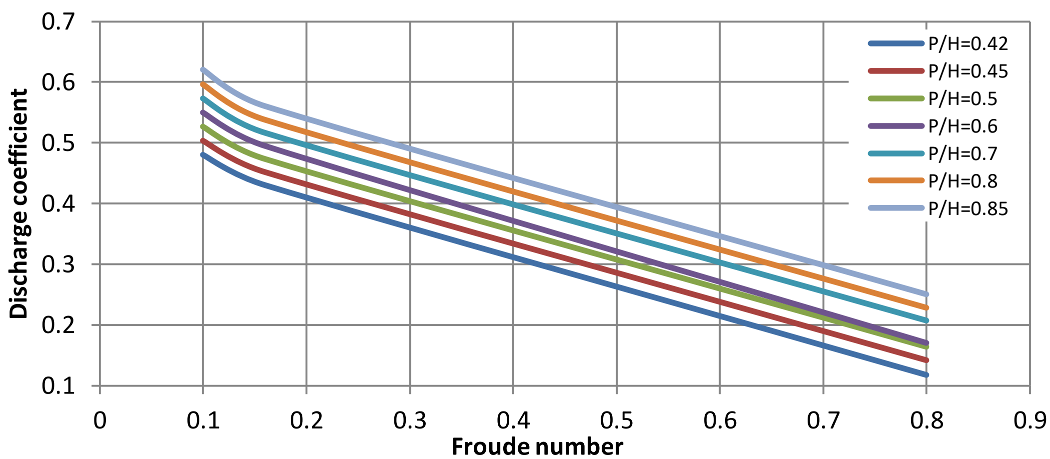

Figure 5: Discharge coefficient against Froude number with different P/H values. For L/B =1.5 (Borghei et al., 1999).

(Mahmodinia, Javan, & Eghbalzadeh, 2014), (Al-Safi, 2020) and others 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) 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 1200, 900,450, 600and 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 (450 and 600) is very significant. But, the effect for larger side weir included angles (1200 and 1500) is less than low labyrinth weir included angle. They found that discharge coefficient is directly proportional to Froude number as shown in Figure 6. 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.

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

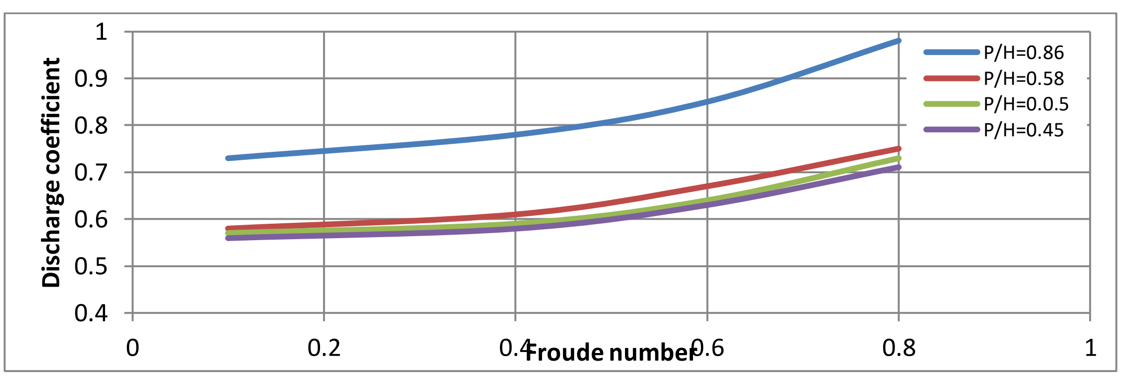

Figure 6: Discharge coefficient against Froude number with different P/H values. For L/B =0.5, L/l = 0.5 (Emiroglu et al., 2010).

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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 1.

Table: I Empirical equation given by researchers

Researchers	Coefficient of discharge	Range of Froude Number	Type of channel/ Side weir
Subramanya, (1972)	$Cd\ = 0.864(1 - F_1^2/2 + F_1^2)^{0.5}$	0.02 to 0.85	
Yu Tech, (1972)	$Cd\ = 0.415 - 0.148\, F_1$		
Nandesamoorthy, (1972)	$Cd\ = 0.288(2 - F_1^2/1 + 2F_1^2)^{0.5}$		
Ranga et al, (1979)	$Cd = \ 0.54 - 0.40\, F_1$	0.10 to 0.50	
Hager, (1987)	$Cd\ = 0.485(2 + F_1^2/2 + 3F_1^2)^{0.5}$	0.0 to 0.87	
Cheong, (1991)	$Cd = 0.30 - 0.14\, F_1^2$	0.28 to 0.78	for trapezoidal channel
Singh et al, (1994)	$Cd = 0.33 - 0.18. F_1 + 0.49\ p/h$	0.23 to 0.43	
Borghei et al, (1999)	$Cd = 0.7 - 0.48\, F_1 - 0.3\frac{p}{h_1} + 0.06\, L/b$	0.1 to 0.9	
Ura et al, (2001)	$Cd\ =\ 0.611\ [\ cos\theta(3F_1^2/2 +\ F_1^2)0.5\ +\ Sin\theta\ (1 - (3F_1^2/2\ +\ F_1^2))0.5]\ sin\theta$		Oblique side weir
Emiroglu et al, (2010)	$Cd = \left[18.6 - 23.535\left(\frac{L}{B}\right)^{0.012} + 6.769\left(\frac{L}{l}\right)^{0.112} - 0.502\left(\frac{p}{h}\right)^{4.024} + 0.094 sin\theta\right]^{-1.431}$	0.1 to 0.8	Single cycle labyrinth side weir

III. Summary and conclusion

The efficiency of the side weirs is evaluated through the discharge coefficient, as the side weir is considered efficient whenever it gives a higher discharge coefficient. The discharge coefficient in side weir depends on a set of parameters according to the dimensional analysis created by the researcher, such as the length of side weir, opening side weir, height of the side weir, width of the side weir crest, the height of the water above the side weir, and the

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shape and width of the main channel. Many researchers have proven that increasing the length of the side weir crest gives an increase in the discharge. Thus, reducing the depth of the water above the crest, leads to a reduction in the velocity head that causes drifts in the body of the transmission channels and the generation of high loads on the body of the structure that require special designs.

In this way, the value of the discharge coefficient increases with the decrease of the Froude number and also increases with the increase in the ratio of the side weir height to the water height on the crest. And the discharge coefficient increases with increasing the ratio of the opening length side weir to the crest width. Therefore, researchers developed the side weir by manipulating the length of the summit and some characteristics to obtain new types of side dams that allow the passage of high quantities of water, especially during floods such as the W shepe, labyrinth and piano key side weir. where these side weirs allow the passage of discharge through them higher than rectangular side weirs with (1.5-7.5) times.

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