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Review of Discharge Cœfficients of Side Weirs

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Abstract

More than eighty years ago, De-Marchi indicated an assumption for hydraulics of flow-through side weir. Many researchers who study side weir depended on this assumption in their studies. Many studies for side weir were carried out in different channels, and numerical studies supported the results. This study deal with a comprehensive review of discharge coefficient for side weir.

Keywords: open channel hydraulics; side weir; discharge coefficient; rectangular side weir

Introduction

The side weir is a structure in open channels where the flow passes from primary to side-channel. It also offers to use as discharge device measurements. (De Marchi, 1934) submit the first significant study that dealt with side weir hydraulics gives an assumption for flow-through side weir, which other authors built on in their studies. Due to the significance of side weirs, a literature survey suggests that their discharge coefficient has been widely investigated. Numerous investigations have been conducted on rectangular sharp-crested side weirs, including work by (Singh & Satyanarayana, 1994), (Singh et al., 1994), (Holley, 1987), (Swamee, 2014), (Shariq et al., 2018), (Muslu et al., 2003), (Venutelli, 2008), (Branch, 2012), (Prakash et al., 2011), (Delkash & Bakhshayesh, 2014), (Bagheri et al., 2014) and (M. Y. Mohammed & Mohammed, 2011). (Ranga Raju et al., 1979) imply that bed slope and friction significantly affect side weir discharge. (For & Borghei, 1999) explored the use of spatially variable flow in rectangular side weirs. Supercritical flow has been investigated in rectangular side weirs by (Ghodsian 2003) and (Durga Rao & Pillai, 2008). The numerical studies carried out in rectangular side weir have been investigated by (A. Y. Mohammed et al., 2014), (A. Y. Mohammed, 2015), (A. Y. Mohammed & Sharifi, 2020), and (A. Y. Mohammed & Golijanek-Jędrzejczyk, 2020). In all previous studies, the discharge coefficient ranged from (0.45-0.77). (Uyumaz & Muslu, 1985), (Granata et al., 2016) and (Khalili & Honar, 2017) were studied side weir in the circular channel, while (Keshavarzi & Ball, 2014), (Wang et al., 2018), (Nemaie et al., 1991), (Rahimpour et al., 2011), (A R Vatankhah, 2014), (Nezami et al., 2015), (Azimi et al., 2017) studied side weir in a trapezoidal channel. The triangular side weir was also reviewed by (Prakash Kumar & Kumar Pathak, 1987), (M. N. Shesha Prakash, 2003), (Azimi & Shabanlou, 2015), (Ali Uyumaz, 1990), (Uyumaz, 2007), (Emiroglu et al., 2010), (Ameri et al., 2015), (Ali R. Vatankhah, 2012). Due to the variety of side weir forms and channel cross sections, it is predicted that several research investigations have been undertaken on diverse geometric shapes. These lead to different values of discharge coefficient because of these different in channel cross section which need to made review of these research and evaluate discharge coefficient for each kind of side weir structures. The current study presents review of publications of side weir in different channels, focusing the discharge coefficient and hydraulic background for every kind of side weir.

Hydraulics of Side Weir

Several articles studied side weir in the rectangular channel. Figure 1 presents a view of a typical rectangular side weir including water surface profile along the longitudinal flow direction.

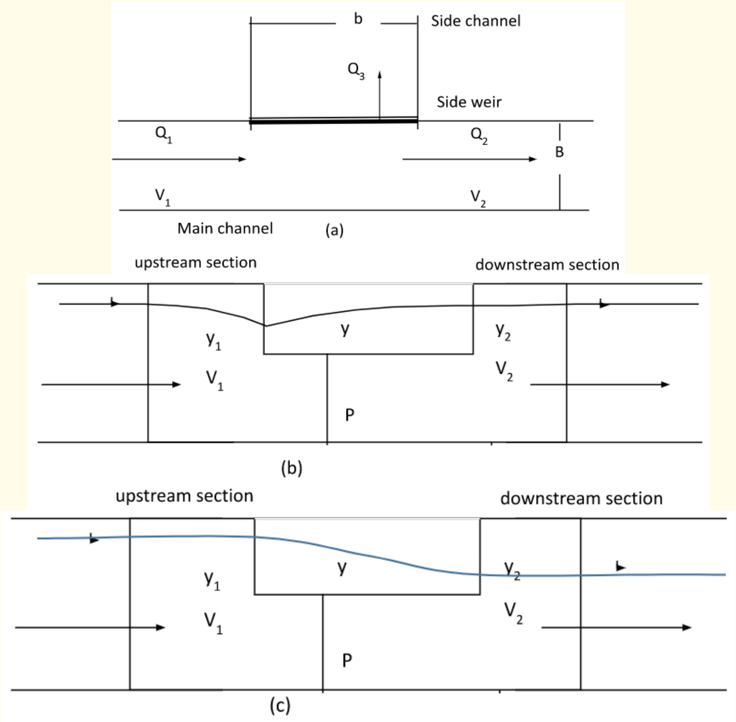

Figure 1: side channel sketch; (a) elevation; (b) plan for subcritical flow; (c) plan for supercritical flow.

Froude number is the most significant element influencing flow over side weir. It implies whether the flow is subcritical or supercritical, affecting water surface flow and hydraulic properties for pressure over side wear. It can be shown in figure 1 (a, b, and c).

Pattern 1 (Figure 1b): The flow is subcritical ($Fr < 1$) through the distance of the side weir; The water level from the upstream end to the downstream end of the side weir appears to be marginally increasing. Consequently, the downstream end discharge strength of the flow is more similar to its upstream end frequency. This state is usually seen in uniform channels and small slope channels.

Pattern 2 (Figure 1c) In this case, the approach flow over the length of the side weir is supercritical ($Fr > 1$). Therefore, from the upstream end of the side weir to the downstream end of the side weir, the water level falls. As a consequence, the flow discharge is larger inlet than the outlet. Generally, in incredibly steep channels, this type of flow exists.

Problem Formulations

Conservation of Mass

According to this law, 'substance cannot be produced or broken, even though it can be converted' Since fluid dynamics may not require any chemical transitions in civilian systems, this can be generalized to mass conservation. This implies that the energy entering a boundary condition is identical to the point exiting the boundary condition, expressed by equation 1 in its simplest form. All fluid-dynamic issues are solved by conserving water. (Chadwick et al., 2004).

$$Q=VA \qquad (1)$$

Where;
Q is discharged; V is velocity, and A is an area of cross-section.

Conservation of Energy:

Energy conservation law states that "energy cannot be produced or lost." It can be converted from one form to another, like kinetic energy. The word "energy loss" is frequently used. However, it only came from the energy wasted via liquid and exchanged to heat via friction losses, such as friction losses. (Chadwick et al., 2004).

The Bernoulli equation has to be the most typical version of the energy equation in hydraulic issues; eq. 2. the Pressure Head, Kinetic Head, and Potential Head.

$$\frac{p1}{\rho 1g} + \frac{u1}{2g} + z1 = \frac{p2}{\rho 2g} + \frac{u2}{2g} + z2 = constant \qquad (2)$$

Where;

P1,2 is upstream and downstream pressure; ρ is density; u1,2 is upstream and downstream velosity; g is gravity's acceleration, and z is elevation.

Many arrangements with side weir approaches incorporate this's application principle. The matter of dispute because the law of momentum appears to be more applicable.

Specific energy

The earlier studies for side weir hydraulics were De-Marchi 1934, which provided the first assumption for side weir flow, specific energy identified one of the critical assumptions on which side weir hydraulic depended, particularly in the rectangular channel.

$$E = y + \frac{Q^2}{2b^2gy^2} \qquad (3)$$

Where;

E is specific energy; y is the depth of water; Q is channel discharge, and b is the width of the main channel.

De Marchi (1934) suspected that the overall flow energy in the main channel would remain unchanged over the length of the weir.

In a side weir with a rectangular shape (Fig. 1 and Eq. 1), De Marchi devised an econometric model to establish the lateral weir drainage relationship. The complex equation of spatially varied flow through a side weir (Chow, 1959).

$$\frac{dy}{dx} = \frac{s_o s_f - \left(\frac{\alpha Q}{gA^2}\right)\left(\frac{dQ}{dx}\right)}{1 - \left(\frac{\alpha Q^2 B}{gA^3}\right)} \qquad (4)$$

Where;

dy/dx is bed-water gradient, x is the latitudinal axis, Sf is the influx of energy, α is the adjustment factor for kinetic energy, A is the flow's area, B is channel width. The following hypotheses are being used to obtain (Eq. 4):

1. It's a rectangular and faceted conduit.
2. Between sections 1 and 2, the lateral weir is narrow, and the specific energy (E) remains constant.
3. With appropriate aeration of the nappe, the weir sides are expected to be precise.
4. The adjustment factor for kinetic energy (α) is assumed to be one.

Considering α=1 and (So-Sf) = 0 (relatively constant energy throughout the weir).

$$\frac{dQ}{dx} = \frac{2}{3} c_{d\sqrt{2g}} (y - p)^{1.5} \quad (5)$$

Where;

dQ/dx is the discharge in a longitudinal direction, y is water depth above weir, p is side weir height, and Cd is the De Marchi discharge coefficient (Chow, 1959). The above equation displays the standard equation used for side weir.

Momentum Preservation

The rule of momentum Preservation notes that "a moving object cannot acquire momentum or waste impetus until it applies any external power.

The motion's second law by Newton is also used in fluid dynamics.

The most basic version of this formula is entering impetus equivalent to leaving momentum, as is seen in eq.6.

$$\rho \delta Q_1 \delta t u_1 = \rho \delta Q_2 \delta t u_2 \quad (6)$$

This equation cannot apply to the side weir problem in this type because the flow is split at the outfall of the surrounding fluid.

As a reason, the formula might be in the format eq.1, with the first phrase becoming the upstream the weir's flow, term two being the flow directly after the weir, and finally, the third phrase reflecting the part of the flow passing across the side weir.

$$\rho \delta Q_1 \delta t u_1 = \rho \delta Q_2 \delta t u_2 + \rho \delta Q_3 \delta t u_3 \quad (7)$$

Discharge Coefficient

The De Marchi discharge coefficient, Cd, is defined as side weir variables in geometry and hydrodynamics.

$$c_d = f\left(F_r, \frac{L}{b}, \frac{p}{y_1}\right) \quad (8)$$

Where;

Fr is the Froude number, L and b are the lengths of the lateral weir and width of a channel. y1 is the weir upstream water depth. P is the height of the sill.

The discharge coefficient of the side weir was analyzed in many papers with various channel shapes, and specific types of Cd equations were submitted based on Froude number and other parameters.

(Borghei et al., 1999), (HONAR & JAVAN, 2008), (Kumar & Pathak, 1987), (Swamee, 1988), (Khalili & Honar, 2017), (Rahul, Pandey, Mittal, S.K., Choudhary, 2016), (Nezami et al., 2015), (Azimi et al., 2015), (Kaya, 2010), (Hager, 1987), (Jalili & Borghei, 1996), (Borghei et al., 1999), (Ranga Raju et al., 1979), (Subramanya & Awasthy, 1972), (Yu-Tech, 1972), (Cheong, 1991) are studied discharge coefficient and the following equations for different authors which predicted side weir Cd calculated. Figure 2 represents the discharge coefficient relationship between values calculated using De-Marchi eq and Eqs. Of other authors, these values ranged between (0.45-0.77).

De-Marchi (1934)	$\frac{2C_dL}{3b} = \frac{2E-3p}{E-p}\left\{\left[\frac{E-y_2}{y_2-p}\right]^{0.5} - \left[\frac{E-y_1}{y_1-p}\right]^{0.5}\right\} - 3\{sin^{-1}[\frac{E-y_2}{y_2-p}]^{0.5} - sin^{-1}[\frac{E-y_1}{y_1-p}]^{0.5}\}$ (9)
Subramanya & Awasthy (1972)	$C_d = 0.864\times\sqrt{\frac{1-F_r^2}{2+F_r^2}}$ (10)
Range Raju et al. (1979)	$C_d = 0.54 - 0.4\times F_r$ (11)
Cheong (1991)	$C_d = 0.45 - 0.22\times F_r^2$ (12)
Hager (1987)	$C_d = 0.485\left(\frac{2+F_r^2}{2+3F_r^2}\right)^{0.5}$ (13)
Singh et al. (1994)	$C_d = \frac{1}{3} - 0.18F_r + 0.49\frac{P}{y}$ (14)
Jalili &Borghei (1996)	$C_d = 0.71 - 0.41F_r - 0.22\frac{P}{y}$ (15)
Borghei et.al. (1999)	$C_d = 0.7 - 0.48F_r - 0.3\frac{P}{y} + 0.06\frac{L}{b}$ (16)
Ali et al. (2018)	$C_d = \left\{1.1308 - 1.5396\left(\frac{P}{L}\right)^{0.0394} - 0.1492\left(F_1\right)^{0.8292} + 0.0105\left(\frac{y_1}{L}\right)^{3.6295} + 0.487\left(\frac{b}{L}\right)^{-0.0357}\right\}^{0.2322}$ (17)
Borghei et al. (2003)	$C_d = 0.82 - 0.38F_r - 0.22\frac{P}{y} + 0.08\frac{L}{b}$ (18)

Rectangular Side Weir

The researches in rectangular side weir were carried out by (For & Borghei, 1999), (Irmak et al., 2005), (Singh & Satyanarayana, 1994), (Ghodsian, 2015), (Singh et al., 1994), (Holley, 1987), (Swamee, 2014), (Shariq et al., 2018), (Muslu et al., 2003), (Venutelli, 2008), (Branch, 2012), (Prakash et al., 2011), (Delkash & Bakhshayesh, 2014), (Ghodsian, 2003), (Bagheri et al., 2014), (Hager, 1991), (Durga Rao & Pillai, 2008), (Azimi & Shabanlou, 2020), (Pathirana et al., 2006), and (Azimi & Shabanlou, 2016) these studied divided according to Froude number, if Fr>1 (supercritical flow), or if Fr<1 (subcritical flow).

For supercritical flow

Durga Rao and Pillai 2008; Ghodsian 2003, (Azimi & Shabanlou, 2020), (Pathirana et al., 2006), and (Azimi & Shabanlou, 2016) studied side weir in different channel shapes at supercritical flow figure 1c.

They found an equation for the discharge coefficient in a rectangular channel shape.

$$C_d = \{\left[\left(0.611 + 0.08\frac{y-p}{p}\right)\left(1 - 0.802F^{0.212}\right)^{0.85}\right]^{-3.984} + \left[1.06\left(1 + \frac{p}{y-p}\right)^{1.5}\left(1 - 0.195F^{0.657}\right)^{1.55}\right]^{-3.984}]^{-0.251} \quad (19)$$

And

$$Cd = 0.9236 - 0.324F_1 + 0.0521F_1^2 \quad (20)$$

The coefficient of discharge is shown to decrease as the Froude number increases. The average speeds in the leading site observed the weir's downstream are higher than those reported upstream, implying that the flow is speeding up in the right direction. They will be due to lowering Water Surface Profile (WSP) from the beginning to the end of the weir.

For high Froude numbers, the rate of change in longitudinal water surface profiles from upstream to a downstream end of the weir is slower than for low Froude numbers.

For subcritical flow

Many discharge coefficient equations were explored, and the best conditions for their use were discovered. The average energy decrease is 3.7 percent. The relationship between Cd and Froude number clearly shows that Cd decreases as the Froude number rises. Cd levels rise with y1/L and b/L but fall with P/L.

For low Froude numbers, a reverse flow was recorded downstream of the bank of the side weir. The reverse flow decreases as the Froude number in the prominent channel rises. The water surface profile along the channel's centerline is smoother than the side weir bank. It was also seen that the water surface profile near the channel's bank was growing in the vicinity of the side weir.

Trapezoidal Side Weir

(Keshavarzi & Ball, 2014), (Wang et al., 2018), (Nemaie et al., 1991), (Rahimpour et al., 2011), (A R Vatankhah, 2014), (Nezami et al., 2015), (Azimi et al., 2017) were studied side weir for trapezoidal channel shapes.

(Keshavarzi & Ball, 2014) proposed a novel equation for estimating the discharge coefficient of flow over a side weir in a trapezoidal channel under subcritical flow Circumstances, taking into account side-weir height and upstream side slope.

The Froude number ranged between 0.08 and 0.8. In trapezoidal channels with varying upstream side-wall slopes, the flowrate coefficient for a thin lateral weir was determined to be a variable of upstream Froude number, weir height to upstream depth, and side-wall slope (F1, p/y0, Z). These three variables are taken into account while calculating the discharge coefficient. As a result, a new equation is proposed.

$$c_d = 0.7 - 0.452F_1 - 0.157\left(\frac{p}{y_o}\right) + 0.045(z) \qquad (21)$$

(Rahimpour et al., 2011), shown that the DeMarchi equation has been demonstrated to be capable of estimating the discharge over a sharp-crested trapezoidal side weir.

Along the trapezoidal lateral weir, it was discovered that the unique energy remained constant. The DeMarchi coefficient of discharge for a trapezoidal side weir in subcritical flow is a function of the main channel's approach. Froude number, main channel width to upstream flow depth, side weir crest length to upstream flow depth, upstream lateral weir elevation, flow elevations for different side inclinations, and various formulae were created.

New discharge coefficient equations were introduced, allowing for the estimation of side weir discharge. The processes for designing and calculating the release of a trapezoidal side weir were also discussed.

$$C_d = 0.618 + 5.614Fr_1^{0.103} - 3.924\left(\frac{B}{y_1}\right)^{-0.085} - 1.26\left(\frac{b}{y_1}\right)^{0.406} + 1.702\left(\frac{s}{y_1}\right)^{2.77} \quad 1:1 \; side \; slope \quad (22)$$

$$C_d = 0.718 + 0.381Fr_1^{1.363} - 7.07\left(\frac{B}{y_1}\right)^{0.407} - 1.376\left(\frac{b}{y_1}\right)^{0.922} + 8.217\left(\frac{s}{y_1}\right)^{0.305} \quad 1:0.67 \quad (23)$$

$$C_d = 0.451 + 28.613Fr_1^{3.49} + 1.226\left(\frac{B}{y_1}\right)^{1.6} + 1.54\left(\frac{b}{y_1}\right)^{1.12} - 3.69\left(\frac{s}{y_1}\right)^{1.48} \quad 1:0.5 \; side \; slope. \quad (24)$$

When a standard side weir is replaced with a trapezoidal side weir, the weir's efficiency skyrockets, this will be achieved by (Nezami et al., 2015).

The effects of dimensionless parameters such as Fr, p/y1, L/b, L0/L, p/L0, and sin (a) on discharge coefficient have been thoroughly investigated.

Varying p/L0 with a = 30, a = 45, and a = 60 and different L/b have been tried with trapezoidal side weirs.

$$C_d = (1.35\times\left(\frac{p}{L}\right)^{0.081} + 0.384\times\left(\frac{L'}{b}\right)^{0.372} + 0.059\times\left(\frac{F_1}{sin(\alpha)}\right)^{2.24} - 1.37\times\left(\frac{p}{y_1}\right)^{0.176}) \times \left(0.979 + 0.755\times\left(\frac{L'}{L}\right)\right) \quad (25)$$

The flow profiles along a side weir in a trapezoidal channel are presented by (A R Vatankhah, 2014) using an analytical solution. Constant specific energy, a constant weir coefficient, and a constant velocity distribution coefficient along the side weir are used to arrive at the answer. In open channels, the efficient analytical method described will be beneficial in assessing and constructing lateral weirs.

Triangular Side Weir

(Prakash Kumar & Kumar Pathak, 1987), (M. N. Shesha Prakash, 2003), (Azimi & Shabanlou, 2015), (Ali Uyumaz, 1990), (Uyumaz, 2007), (Emiroglu et al., 2010), (Ameri et al., 2015) and (Ali R. Vatankhah, 2012) weir studied side weir in triangular channel shapes.

(Prakash Kumar & Kumar Pathak, 1987) presented relationship between discharge coefficient Cd and main channel Froude number for triangular sharp-crested side weirs; this relationship is modified for broad crested triangular side weirs by a multiplying factor K that is only dependent on the h/L ratio.

$$C_d = 0.668 - 0.381F; for\ \theta = 60^o \quad (26)$$

$$C_d = 0.619 - 0.203F; for\ \theta = 90^o \quad (27)$$

$$C_d = 0.642 - 0.042F; for\ \theta = 120^o \quad (28)$$

The relative increase in flow rate with growth in the head in a steep triangular weir is superior to other categories of weirs. According to research (M. N. Shesha Prakash, 2003), it is preferred over other steep weirs as a stream monitoring instrument in hydraulic, irrigation, and chemical engineering.

Its straightforward geometric design makes it simple to manufacture and popular among flow metering equipment; the increased coefficient of discharge of inclined triangular weirs improves the flow-measuring instrument.

It decreases afflux and expedites the outflow of extra energy; furthermore, the amount of freeboard in irrigation canals when weirs of this kind are installed could be dropped, enhancing its cost-effectiveness. It is also recommended that these slanting weirs be used in existing channels with less freeboard during flood seasons.

(Uyumaz, 2007) Presented theoretical approaches for determining flow profiles and discharges along a side weir in a triangular-shaped channel have been described. Theoretical approaches indicate that the WSP near the axis of the primary channel rises from the beginning to the end in subcritical regimes. but the converse occurs in supercritical regimes.

Circular Side Weir

(Khalili & Honar, 2017), (Uyumaz & Muslu, 1985), (Granata et al., 2016), (Hager 1994) studied side weir in circular channel shapes.

(Hager, 1994) presented flow through a circular-cross-section prismatic side weir keeping the primary focusing on calculating water surface profile, discharge coefficient and study forming hydraulic jump along the side weir and give equations for calculating with a comparison of experimental study (Uyumaz & Muslu, 1985), Using theoretical techniques, estimating flow profiles and discharges via a side weir in a circular channel. The water surface profile has been examined in a subcritical regime. The water profile at the central canal axis increases upstream to downstream, but the water profile rises upstream in the supercritical flow.

A second-degree curve for a subcritical regime and a straight line for a supercritical regime may be seen in the variation of cd concerning the Froude number.

(Granata et al., 2016) demonstrates the use of a commercial TSI Particle Image Velocimetry (PIV) system to investigate the flow pattern in a circular conduit along a lateral weir. The experiments were limited to flows that were just faintly supercritical. An image processing approach was used to get free surface profiles. They look as concave and then convex decreasing curves. For free surface representation, an empirical equation has been presented. An entropic method may accurately forecast longitudinal velocity profiles along the side weir.

An uneven trending curve comparable to the Log-Normal function can illustrate a velocity profile. The peak discharge usually occurs between 30 and 50 percent of the way down the weir. From upstream to downstream, the elementary discharge coefficient grows substantially.

A ten to twenty-five percent saving in energy head was reported in the examined setups. The majority of the head variation occurs in the weir's middle section. Finally, the flow power diminishes along the weir according to a non-linear function.

A semi-circular labyrinth lateral weir type was tested by (Khalili & Honar, 2017) for three heights and three radii in a complete laboratory investigation. The runoff coefficient of the labyrinth's quasi lateral weirs was predicted using empirical formulae. Cd is dependent on dimensionless factors r/b, Fr1, r/p, (y1-p)/r, and (y2-p)/r, according to the proposed equation (non-linear equation).

$$C_d = 0.7874 + 0.379\left(\frac{r}{b}\right) - 0.3383Fr_1 - 0.0466\left(\frac{r}{p}\right) + 0.0276\left(\frac{b}{y_2}\right) - 2.052\left(\frac{y_1-p}{r}\right) + 0.161\left(\frac{y_2-p}{r}\right) \quad (29)$$

$$C_d = 0.99\{(1.02 + 254.31\left(\frac{r}{b}\right)^{37.5} - 0.5Fr_1^{1.9} - 0.001\left(\frac{r}{p}\right)^{2.38} 2.915\left(\frac{y_1-p}{r}\right)^{0.557} + 2.314\left(\frac{y_2-p}{r}\right)^{0.533}\}^{1.023} \quad (30)$$

Conclusion

The side weir structures consider necessary measurement and control devices in open channel flow for different channel shapes. The flow variation above the side weir for subcritical or supercritical flow depends on the Froude number. The most critical parameters affect the side weir's hydraulic characteristics. The theoretical methodology of side weir consists of mass conservation, energy conservation, specific energy, and momentum conservation. The flow rate coefficient for the lateral weir depends on the shape of the channel.

1. In rectangular side weir, the upstream Froude number and the ratio of sill height to upstream flow depth are discovered to influence the side weir's discharge coefficient Cd, which has a mean value of 0.61 and a standard deviation 0.09.
2. In a triangular side weir, the discharge coefficient is 1.5-4.5 times that of a rectangular side weir, and it grows as the crest length and height to channel width ratio grow. Cd levels are highest on the side weir with = 45°.
3. The outflow coefficient alongside weir in trapezoidal waterways with varied inlet side-wall slopes is a factor of the ahead Froude number and the ratio of the weir elevation to above depth and side-wall slope.
4. The circular side weir has a more significant discharge coefficient than the rectangular side weir. The discharge coefficient increases as the radius and crest height to channel width ratio increases.

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