Discharge Coefficient of the Pivot Weir: A Review

1.Abstract

Weirs are one of the structures that are used for flow measurements. A pivot weir is one of these structures. It may be defined as a thin rectangular plate that tilts at different angles from the vertical axis placed in the middle of the channel. The current study was conducted to identify the studies that used this type of weir to discharge coefficient investigation. The results referred to reducing discharge coefficient in lateral contractions and increases as the weir inclination angle increases. Research has also demonstrated that the discharge coefficient is lower when two neighbouring weirs are used with the same inclination angle than when they are used with different angles. The results also show that the shape of the crest of the semi-circular pivot weir increases the value of the coefficient of discharge compared to the shape of the sharp and circular crest.

Keywords: pivot weirs, angle of inclination, inclined weir length, and coefficient of discharge.

2. Pivot weir

A pivot weir can be defined as an inclination rectangular weir Figure (1) (Prakash et al., 2011). It is one of the important hydraulic structures that are created in open channels towards the flow, as it is used in irrigation networks for the purpose of regulating the water level, due to its ease of use and operation (Sheikh Rezazadeh et al., 2016). It is also used in measuring discharge and controlling the water depth level (Bijankhan & Ferro,2020) as shown in Figure (2). Summit shape, channel width, and weir inclination angle are the main factors affecting runoff over pivot weir (Bijankhan & Ferro, 2017).

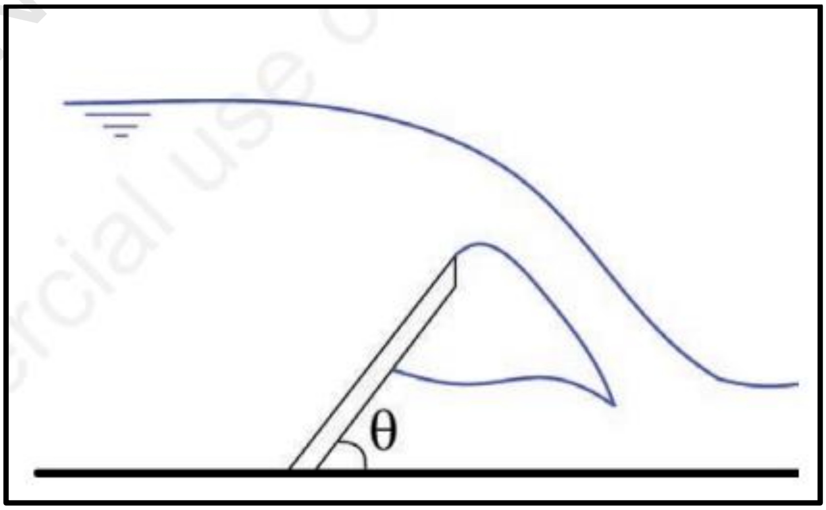

Figure (1): sketch pivot weir (Prakash et al., 2011).

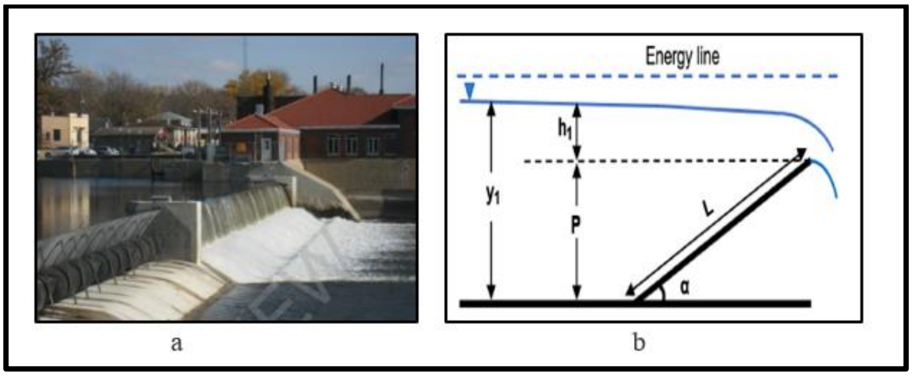

Figure (2) pivot weir: a. (Renau Rubio ,2024). b. Hajimirzaie & González, 2021).

Where:

L: inclined weir length (L)

P: height of weir.

h_1: head over weir.

∝ : angle of inclination weir.

3. Introduction

Water is one of the natural resources for which the demand is constantly increasing. To preserve and use them in proportion to the water crisis at present, weirs have been used, which have multiple benefits, including measuring and controlling flow. The pivot weir is one of the most recently used types of weirs (Sinclair, 2021). There are several advantages to the pivot weir, as it is used to control the level of water and can be used as a gate. It is also used in inspecting facilities when the loss of charge is small and when the facility requires high accuracy. It is used to remove sediments that collect downstream weir, as well as in water management due to its ease of use and control in sites, as it can be operated remotely when it is linked to main control devices to obtain the required data (Nikou et al., 2016). It is also known as overshot gates and began to be used in the late twentieth century (Wahlin & Replogle,1994 ؛ Stringam& Gill,2012 ؛ Lee et al. 2014 and Borghei et al.,2003). The researcher (Hulsing ,1968) Study the angle of inclination effect on the discharge coefficient. angles of inclination are (45, 56, and 71.6°), the conclude the greater of the angles leads to the greater of the discharge coefficient compared to the normal weir. researcher (Manz ,1985) developed the systems for transporting irrigation water using the pivot weir Model (ICSS) for pivot weir computerization . He found a relationship depending on the coefficient of influence angle inclination of the pivot weir under free-flow conditions equation (1).

$C_a = -10^{-12} \times 5.89\theta^{6} + 10^{-9} \times 1.202\theta^{5} - 10^{-8} \times 8.35\theta^{4} + 10^{-6} \times 3.422\theta^{3} - 10^{-4} * 2.217\theta^{2} + 10^{-3} \times 9.035\theta + 1$ ………………….....……………………………………………. (1).

Where:

Ca: the effective coefficient of the angle.

θ: angle of inclination weir.

(Norasteh & Monem ,2011) conducted a study for pivot weir using Fuzzy Automatic Control This work uses a fuzzy algorithm to automatically adjust the water level on a pivot weir. This system was built in a lab setting and assessed in high-flow conditions. According to the results, variations stabilize in less than two minutes, with the highest absolute error falling between 6.9 and 9.2% and the cumulative absolute error values between 0.79 and 1.17% in high flow variations (400%). The researchers (Prakash et al., 2011) developed the head-discharge-inclination model to measure flow over inclined Rectangular weir. the limitation of this study are angles of inclination are (0^0, 15^0, 30^0, 45^0, and 60^0) and actual discharge is from 0.0012 -0.021 m^3/s. The results show that the coefficient of discharge increases with an increase in the angle of inclination of the weir equation (2).

$$C_d = 0.0005\alpha^2 - 0.0111\alpha + 1.0478 \quad \text{(2).}$$

Where:

C_d: coefficient of discharge.

an empirical equation for discharge with head water for different inclination angles is shown in Table below.

Table (1): empirical equation for discharge with water head

S.No	α	$Q=KH^n$
1	0	$Q = 0.039\ H^{1.552}$
2	15	$Q = 0.040\ H^{1.486}$
3	30	$Q = 0.046\ H^{1.548}$
4	45	$Q = 0.056\ H^{1.564}$
5	60	$Q = 0.077\ H^{1.444}$

Where:

H: Total energy upstream of the weir (L).

K&n: constant.

The researchers (Arvanaghi et al., 2014) conducted a laboratory study to find effect of changing the inclination angle of pivot weir on the coefficient of discharge. pivot weir angles are (0, 15, 30, and 45°). To Evaluating discharge equation under Submerged Flow Conditions pivot weir (Nikou et.al. 2015 a), Using experimental data from the United States Bureau of Reclamation (USBOR). three pivot weirs with various three-side contractions were assembled. The inclination angle is between 16-90^0 Weir's height is between 0.13-0.6m Reynolds's number is between 10^4-$2*10^5$, In contrast to Brater and King's relation with ±40% error, which has good precision, the discharge coefficient was compared with experimental data for a submerged flow condition where the submergence factor was between 0.2 and 0.9 and the range of error was less than ±20%.(Nikou et.al., 2015 b) Estimate Discharge equation to the head for Pivot Weirs with variable Side Contractions The value of discharge is between (350-880 l/s). inclination angles (15-50°) The Head-Discharge Equation (3,4,5) following:

$$\alpha = -3.453\left(\frac{b}{B}\right)^3 + 6.119\left(\frac{b}{B}\right)^2 - 3.214\left(\frac{b}{B}\right) + 1.23 \qquad \text{……………………………….……….(3).}$$

$$\beta = -0.984\left(\frac{b}{B}\right)^2 + 1.452\left(\frac{b}{B}\right) + 0.508 \qquad \text{………………………………..…………(4).}$$

$$Q = b\sqrt{\left(\alpha\left(\frac{h}{P}\right)^{\beta} P\right)^3 g} \qquad \text{…………………………………....…..(5).}$$

Where:

b: width of the weir (L).

B: width of the channel (L).

h: Depth of water upstream of the weir (L).

g: acceleration due to gravity (L/T^2)

Q: discharge (L^3/T).

β: angle of inclination weir.

the researchers (Sheikh Rezazadeh Nikou et al., 2016 a) evaluate the equation (6) for the head – discharge equation over the pivot weir. they used Six different angles (0, 20, 40, 60, 80, and 90°) and three different contractions (0.4, 0.6, and 0.8), also discharges ranging from (20 –17.4) l/s.

$$Q = C_t\,[2\sqrt{2g}\,B\,y_u^{3/2}\,(\sqrt{\cos\{\tfrac{1}{3}\,tan^{-1}\frac{[\sqrt{y_u^2-(y_u-p)2}\,]}{(y_u-P)}\}})^3] \qquad \text{……………………..………..(6).}$$

Where:

C_t: discharge coefficient for second approach

y_u: Depth of water upstream of the weir (L).

The effect of vertical contraction begins when the angle is greater than 40°, and the discharge coefficient increases by 44.6% when the angle decreases from 90° to 40°. It is within limits 61.7% when the weir inclination angle decreases from 40 ° to 20°, and ranges developed equations for submerged and non-submerged flow from 36.7 to 54.6% when the lateral stenosis increases by 0.4. Researchers (Sheikh Rezazadeh Nikou et al., 2016 b) conducted a laboratory study in which they for three types of weirs, including the pivot weir, based on dimensional analysis, energy equation, and critical depth. They reached to submerged equation (7).

$Qs = Qf *[1- (\frac{yt}{yo}) ^\omega] ^\psi$ ……………………………..……………………….……………(7).

Where:

Q_s: submerged flow(L^3/T).

Q_f: free flow(L^3/T)..

Y_t & Y_o: upstream and downstream depth of flow relative to channel bed respectively (L).

ω & ψ: constants calculated according to type of weir.

Researchers (Di Stefano et al. 2016) have concluded that if the ratio h/p > 1, the level-discharge relationship does not depend on the angle of inclination of the weir. Researchers (Bijankhan & Ferro, 2017) have found a theoretical equation to calculate the level - discharge theoretically using the pivot weir, and they have also deduced equations (8,9,10) to calculate the constants.

$\frac{Ks}{P} = a(\frac{h}{P})^m$ ………………………………………………………………………..…(8).

$a= 0.7732 – 2.10^{-5}\,\theta^2 – 0.0003\theta$……………………………………………………………(9).

$m= 0.9980 – 3.10^{-5}\,\theta^2 + 0.0005\,\theta$…………………………………………………………(10).

where:

a & m: constant numerical.

ks: critical depth defined by

$ks = Q^{2/3} / (B^{2/3}\, g^{1/3})$.

The researchers (Prakash et al. 2018) Studied the effect of the inclination angle on the discharge coefficient, they used inclination Angles (0°, 15°, 30°, 45°, 60° ,75°). The results of this study showed that as the inclination angle increased, the discharge coefficient increased Figure (3).

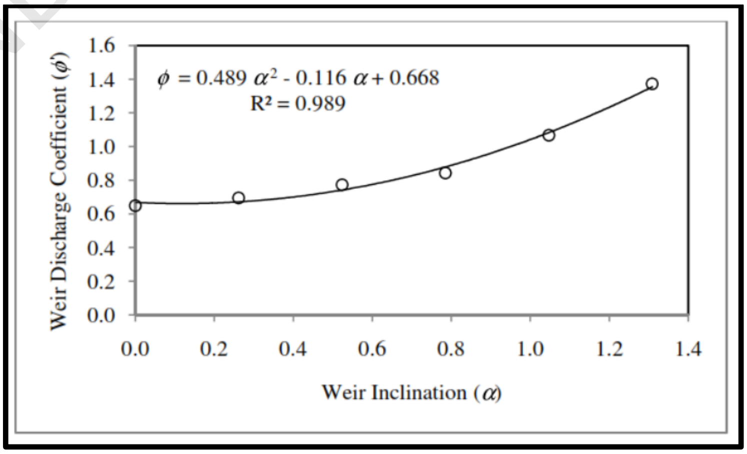

Figure (3): discharge coefficient with respect to the weir inclination

To evaluat discharge coefficient (Azimfar et al. 2018) reached an analytical equations and compared the results with the denominator obtained experimentally. angle of the diversion weir is between 16.2^0 to 90^0. depth of water on the weir to weir height is from 0.09 to 1.9 for free and submerge flow types. The results showed that the used equations are less complex and highly accurate in calculating the discharge coefficient compared to the results of previous studies Figure (4).

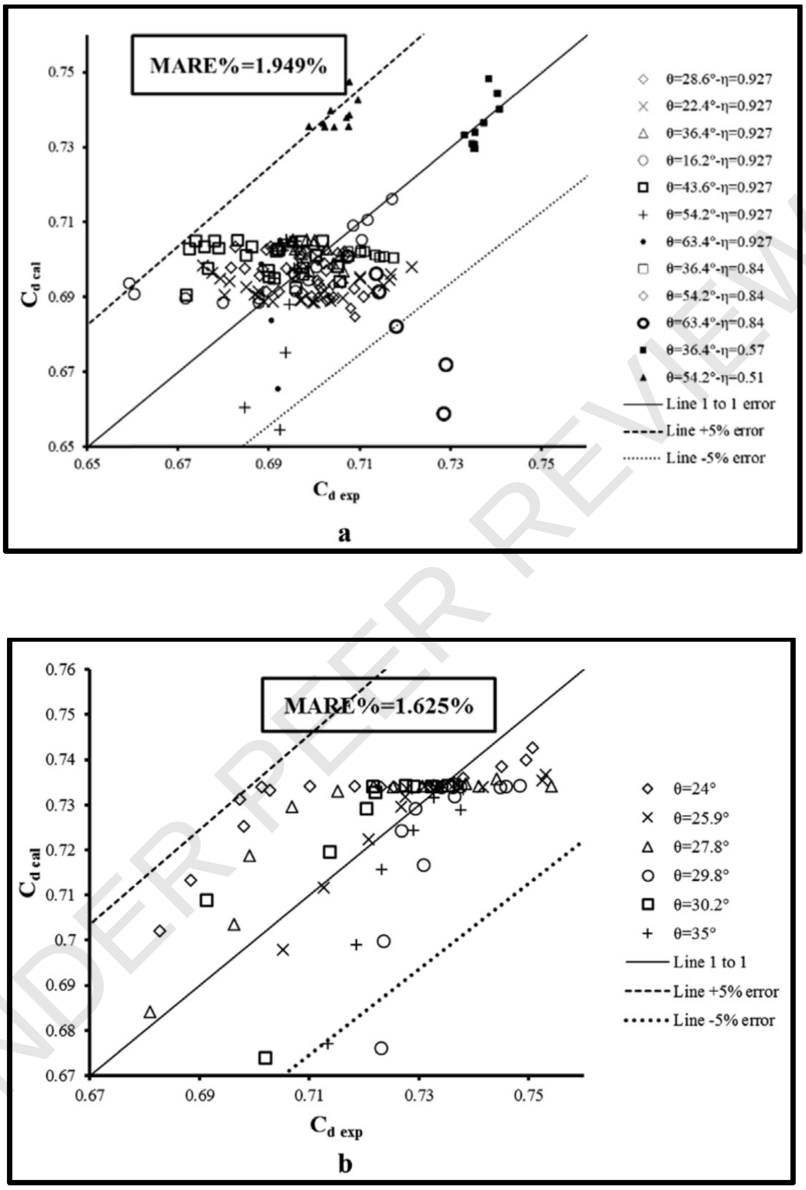

Figure (4) relationship between cd exp and cd act

MARE using momentum method under free-flow conditions for: (a) Armtec weir; (b). USWCL weir

MARE**:** mean absolute relative error.

USWCL: type of gate**.**

The research (Şimsek ,2020) used umerical modelling of an inclination angles pivot weir (900, 71.60, 56.30, 450, 26.60 & 14.0). Reynolds Stress Model gives successful results in flow with curvature of flow lines, with different angles. the researchers (Bijankhan and Ferro ,2020) studied Submerged Pivot Weir by using experimental Modeling. weir inclination angles are (39.6°, 53°, 85°, and 90°) and weir heights from 0.263 to 0.312. the results showed that pivot weir may be submerged until when tail water under weir height Figure (5).

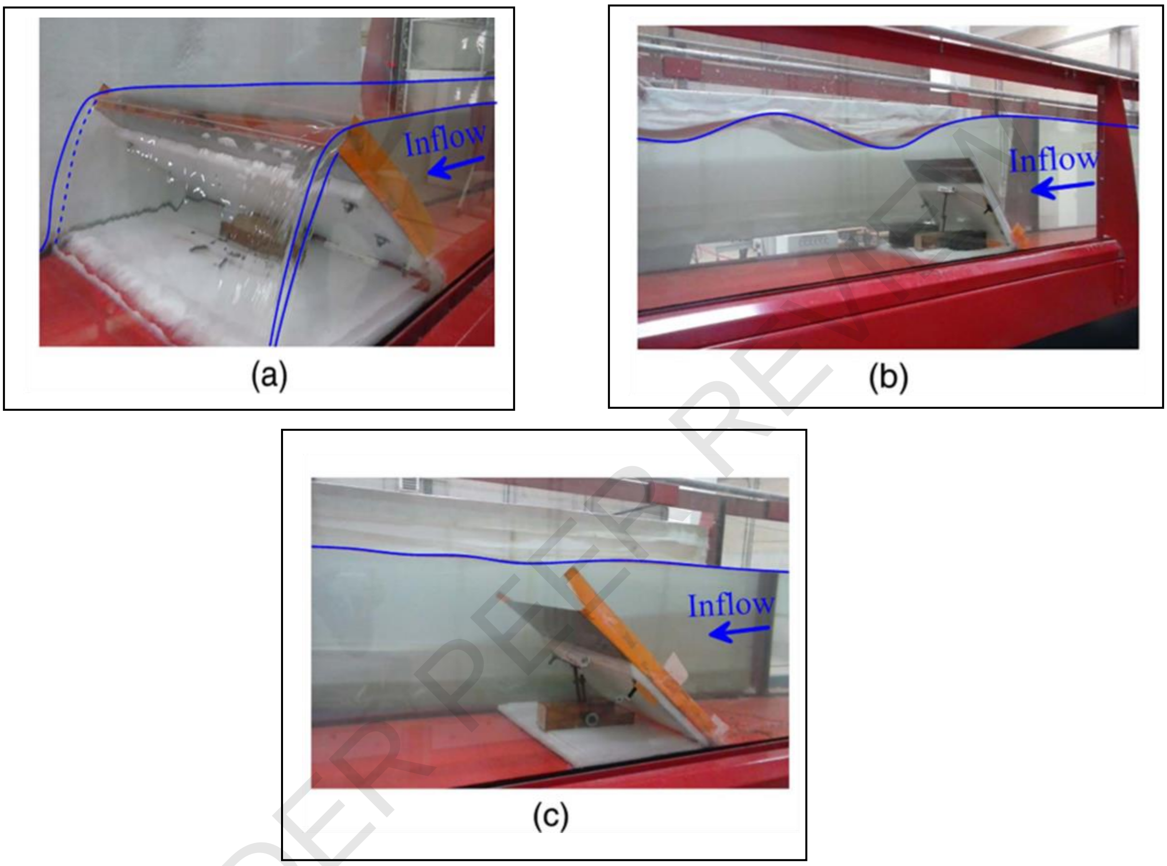

Figure (5):effect tailwater depth on flow downstream inclined rectagular weir
(a)free flow ;(b)submerged flow;(c)full submerged flow

The researchers (Hajimirzaie &González Castro, 2021) conducted Experimental Modeling of Submerged pivot weir by using a discharge value ranging between 2.45m3/s to 28.3 m3/s. they presented a rating formula (11), for flow over a pivot weir and calibrated with experimental data.

$$Cd = 0.708 - 1.5\left(\frac{b}{B}\right) \propto^3 \left(\frac{h1}{L}\right)^3 + 2\left(\frac{b}{B}\right) \propto^6 \left(\frac{h1}{L}\right)^6 \ldots\ldots(11).$$

in order to investigate the free flow over the pivot weir in the form of an inclined rectangle, the researchers (Mahdavi &Shahkarami ,2020) used a numerical study based on the particle hydrodynamics (SPH). the value of discharge Ranging from 0.06 to 0.33 m^2/s , gate openings are 0.3,0.5 &0.7m.also length of the weir are 0.3,0.4 &0.6m. the results of this study showed that SPH shows that the decreasing reservoir head is predicted by activating the correction term Figure (6).

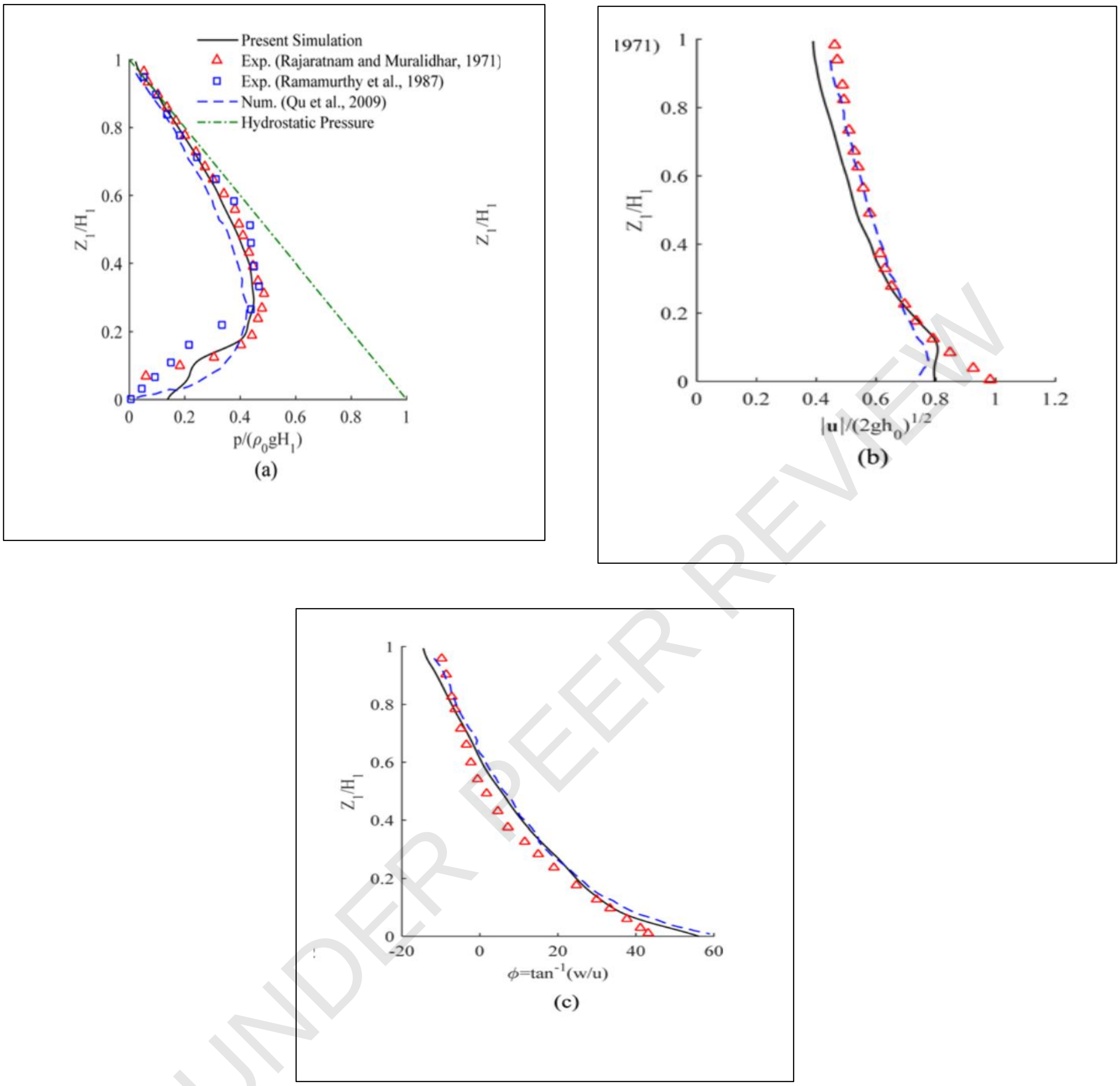

Figure (6): Experimental and numerical results for (a)pressure ; (b)velocity & ; (c) velocity angle

The researchers (Baratov et.al. 2021) studied effect of pivot weir to controlling water levels upstream and downstream canals using Modelling equation and simulation. the mathematical model of the water levels control is developed using by Matlab's tool Simulink Figure (7).

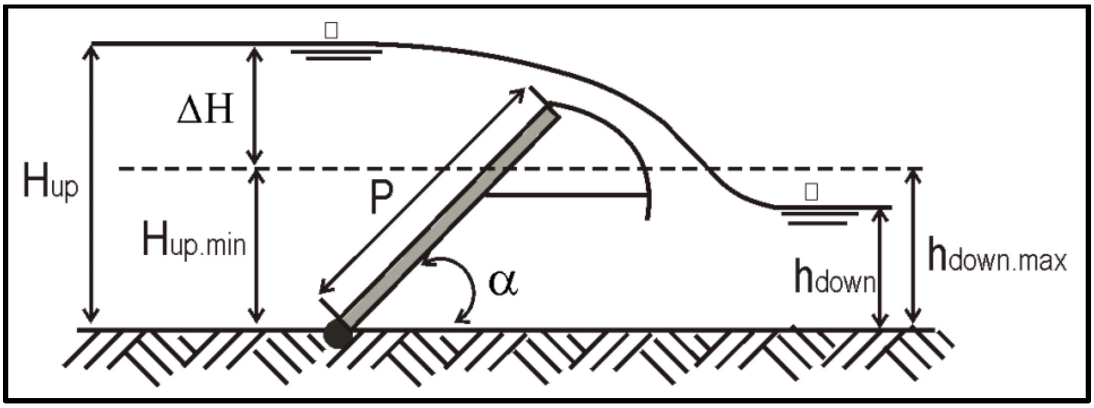

Figure (7): A pivot weir in open canals

the mathematical model of the water levels control in open canals is developed using by Matlab's tool Simulink Figure (8). The results showed that agood agreement.

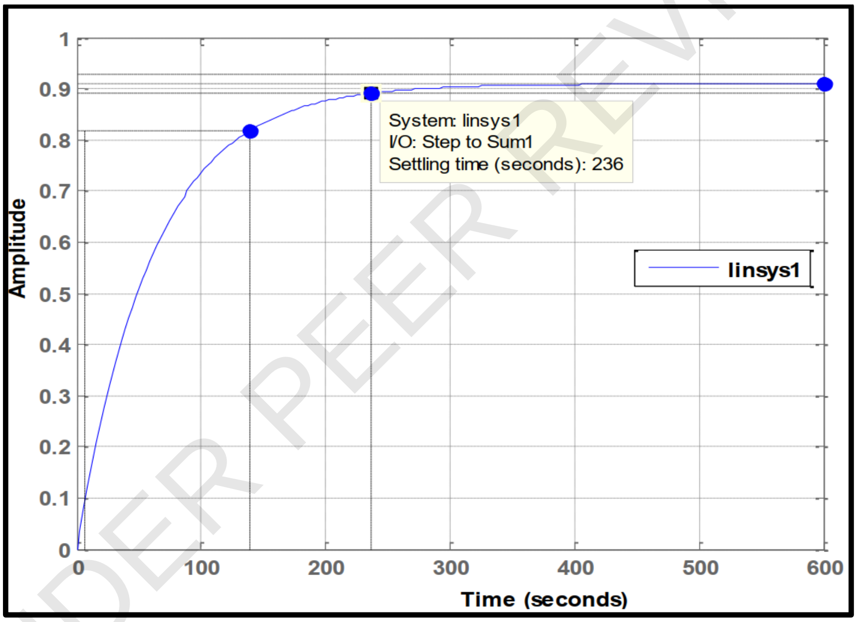

Figure (8): response of modle system

the researcher (Sinclair ,2021) studied a comparison between the sharp-crested weir and pivot weir using CFD and the effect of angles of inclination of the pivot weir on the amount of discharge coefficient. he used five different angles (27°, 47°, 57°, 72°, and 90°) and six different values of the discharge.the results showed that The highest value of the discharge coefficient was at an angle 27°. to study Characteristics of discharge and numerical model the researcher (Zerihun ,2022) For numerical computations, empirical equations were developed by applying a non-linear optimization technique. These equations are valid for $0.1 \leq h / w < 6.5$ and for $26^{o} \leq \theta < 90^{o}$.the results showed that a relative overflow depth affects the characteristics of curvilinear trans critical flow and coefficient of discharge. also the inclination angle has an influence on haracteristics of flow at full-width gate with a face slope flatter than 56°.the researchers (Khatamipour et al.2022 a) identifying the hydraulic characteristics of the pivot weir. three pivot weirs in the watercourse at the same level. Three different shapes of the crest weir were studied: sharp crest, circular and semi-circular Figure (9).

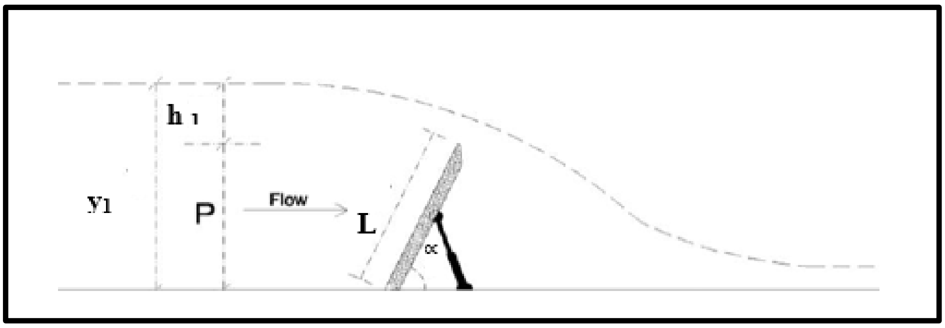

Figure (9): a pivot weir in the water way

The results showed that weirs with an inclination angle of 70° and the semi-circular crest give the highest discharge coefficient.to study Numerical Flow Characteristics over pivot Weirs, the researchers (Khatamipour et.al, 2022 b) used Flow discharge 61.5 l/s to 149.6 l/s Inclination angle 22.40 to 63.40. They found a relationship as shown equation (6):

Ca=0.9364 + 0.0042 θ - 0.00004θ2 ……………………………………………..……...(6).

Also, the study shows that the discharge coefficient increases with the inclination angle up to 1.076 Figure (10).

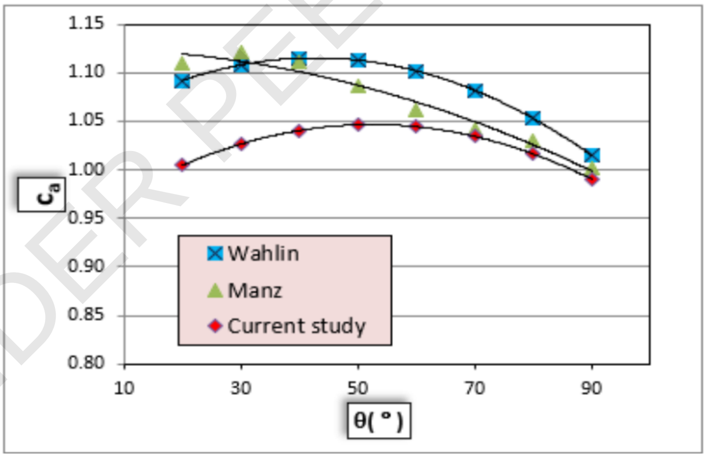

Figure (10): compare many studies between effective coefficient of the angle Ca and inclination angle θ.

The researchers (Khatamipour et al, 2023) Using pivot weir in conditions of flooding and drought two pivot weirs with angles (27.8-90°) and discharge (40-130 l/s) Figure (11).

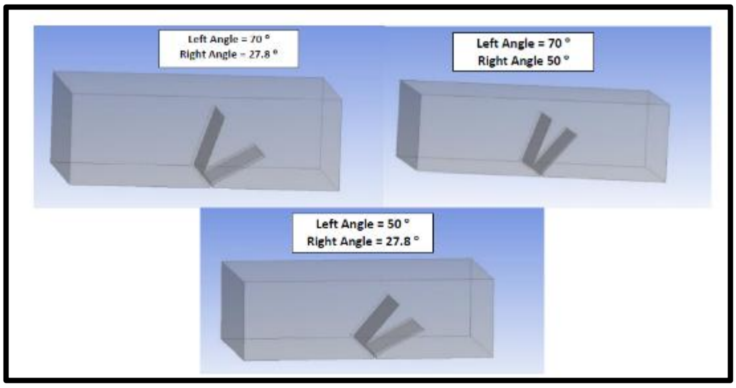

Figure (11) two pivot weir at different inclination

The researchers (Pugh et.al, 2024) conducted a comparative study between pivot and vertical weirs. Angle of inclination is between 25^0 to 90^0.weir vertical height is between 65mm to 150mm. Reynolds number is between $1.6*10^2$ to $9.6*10^4$, Figure (12).

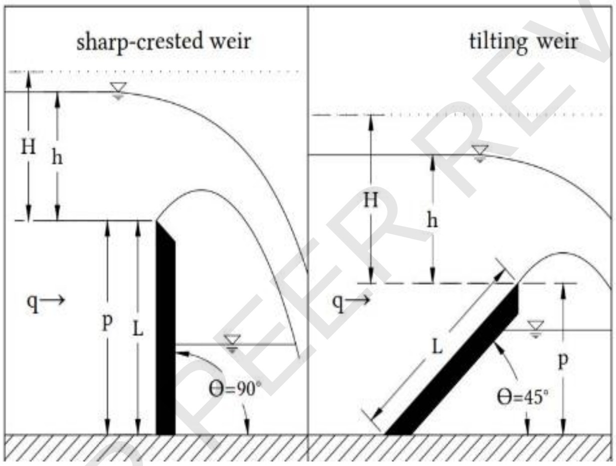

Figure (12): flow over vertical and pivot weir

The results showed when the ratio between the angle of deviation of the weir from the right side to the angle of deviation of the weir from the left side is equal to 1 the results of the experiments give good values that are consistent with the results obtained from the Anass CFX program. When the ratio between the angle of deviation of the right weir to the angle of deviation of the left weir is not equal to 1 the coefficient of influence of the angle increases from 28.1 to 31.1%.

in order to avoid water scarcity at the present time and control the water level in open channels and measure it with high accuracy and with the least possible energy, modern and smart technology systems have been used. Since some of the methods used are simple and primitive and can consume energy, the researcher (Baratov et.al, 2021) studied pivot weir, which is considered one of the methods used in measuring flow and controlling the water level in channels, Figure (13). The results of the study showed that pivot weir reduces energy consumption by twice the amount of using the sliding gate with vertical openings. It also has the ability to measure water and control its level with high accuracy, and has the ability to control large flows. Thus, it increases the efficiency of water distribution systems and reduces the useless distribution that causes water.

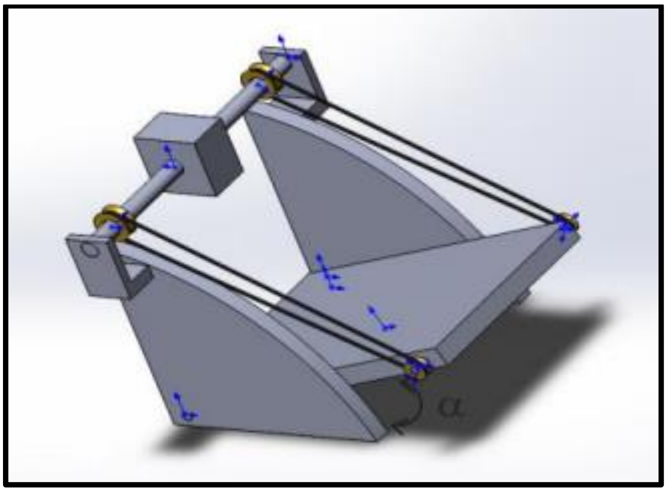

Figure (13): pivot weir desighn

Researchers (Hutchinson et.al, 2024) developed the pivot weir equation to measure the flow when the free flow of the gate edge is immersed in the flow direction causing an inaccurate estimate of the flow. The equation gave good results but required the use of variables following the equation used.

4. Conclusions

from this study that the discharge coefficient rises with an increase in the weir slope angle and decreases with lateral contractions. The impact of various angles on the discharge coefficient was ascertained using the ANSYS CFX software. Studies also showed that in the case of using two weirs with the same slope angle, it is less than in the case of using different angles for two adjacent weirs. The results also showed that the semicircular pivot weir crest shape increases the value of the discharge coefficient compared to the sharp and circular crest shape. A relationship was found that depends on the coefficient of the influence of the slope angle of the weir. A positional relationship was found for the discharge with the water height above the edge of the weir for each slope angle. it Find a relationship depending on the coefficient of influence angle inclination of the pivot weir under free-flow conditions. also used a fuzzy algorithm to automatically adjust the water level on a pivot weir. reached to an empirical equation for discharge with head water for different inclination angles. some researchers developed equations for submerged and non-submerged flow. the results showed that pivot weir may be submerged until when tail water under weir height. t was also used Modelling equation and simulation. the mathematical model of the water levels control is developed using by Matlab's tool Simulink.ad using CFD and the effect of angles of inclination of the pivot weir on the amount of discharge coefficient. It foud that a pivot weir reduces energy consumption by twice the amount of using the sliding gate with vertical openings.

5. List of abbreviations

a & m	constant numerical.
B	width of the channel (L)
b	width of the weir (L)
C_a	the effective coefficient of the angle
C_d	coefficient of discharge
C_t	discharge coefficient for the second approach.
g	acceleration due to gravity (L/T^2).
h_1	head over weir.
h, & y_u	Depth of water upstream of the weir (L).
H	Total energy upstream of the weir (L) .
K &n	Constant.
ks	critical depth(L)
L	inclined weir length (L).
P & *w*	height of weir (L).
Q	discharge (L^3/T).
Q_f	free flow(L^3/T).
Q_s	submerged flow(L^3/T).
Y_t & Y_o	upstream and downstream depth of flow relative to channel bed respectively(L).
y_1	h_1+P (L).
Z	gate opening (L).
α, β & θ	angle of inclination weir
ω & ψ:	constants calculated according to type of weir.
MARE	mean absolute relative error.
USWCL	: type of gate.

6. References

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