**Discharge Coefficient of the Pivot Weir: A Review**

**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.

**Introduction**

Water is one of the natural resources for which the demand is constantly increasing. To preserve and use it in proportion to the current water crisis, weirs have been implemented due to their multiple benefits, including measuring and controlling flow. Among the various types pivot weirs also known as overshot gates emerged as an innovative solution in the late twentieth century (Wahlin & Replogle, 1994; Borghei et al., 2003; Stringam & Gill, 2012; Lee et al., 2014). These weirs provide effective control over water levels and flow rates, making them ideal for modern water management systems.

A pivot weir can be defined as an inclined rectangular weir (Prakash et al., 2011). It is one of essential hydraulic structures created in open channels to regulate water flow due to its simplicity in operation and easy of use. It is also used to discharge measurement and water depth level control (Bijankhan & Ferro, 2020) fig. (1). The primary factors influencing runoff over a pivot weir include the top shape channel width and inclination angle (Bijankhan & Ferro, 2017). Nikou et al. (2016a) presented several advantages of the pivot weir such as its control water levels function as a gate and facilitate facility inspections when minimal charge loss occurs. it is effective in sediment removal in situations requiring high precision. Furthermore, its compatibility with remote operation when integrated with main control devices enhances its applicability in modern water management. Nikou et al. (2016c) explored the hydraulic characteristics of pivot weirs by examining two discharge equation approaches. Their study involved experimental tests on models of pivot weirs with varying angles (0°–90°) and side contractions (0.4, 0.6, 0.8). Using data from the United States Bureau of Reclamation (USBR) they calculate discharge coefficients achieving an accuracy of 15% and 10% for free flow while the submerged flow error remained below 20%, confirming the reliability of their equations. Stefano et al. (2016) employing dimensional analysis and incomplete self similarity theory to study the outflow process of weirs with irregular shapes. They derived a new theoretical stage discharge relationship that comprehensively describes the weir outflow process under various flow conditions and geometries. This relationship was subsequently calibrated using experimental data from existing literature. Hutchinson et al. (2024) studied the potential for reducing uncertainty in fault identification and root cause analysis of water balance anomalies. The study leveraged infrastructural data and expertise from the Murrumbidgee irrigation area in NSW. They found that when the gate tip is submerged below the downstream water level the free flow equation for a pivot weir tends to overestimate flow leading to water balance anomalies. Rubio & Alejandro (2024) focused on cavitation phenomena in hydraulic structures particularly in flap gate spillways widely used in northern regions for discharging floating debris. Their study aimed to explore various discharge conditions and assess the effectiveness of aerating the cavity beneath the jet at atmospheric pressure as a solution. Their findings could significantly impact the design and construction of safer more durable and more efficient hydraulic structures advancing the field of hydraulic engineering.

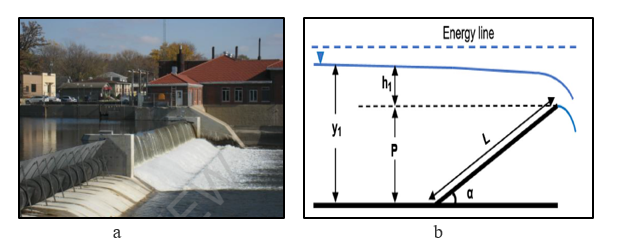


Figure (1) pivot weir: a. (Sinclair, 2021), b. Hajimirzaie & González , 2021).

**Table 1: summery of literature review**

| NO | study | purpose | limitation | results |
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| 1 | Hulsing (1967) | Study the angle of inclination effect on the discharge coefficient. | angles of inclination are ( 45, 56, and 71.6°) | the greater of the angles leads to the greater of the discharge coefficient compared to the normal weir. |
| 2 | 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  Ca = -10−12 ×5.89θ 6 +10−9 ×1.202θ 5 −10−8 ×8.35θ 4 +10−6 × 3.422θ 3 −10−4 \*2.217θ 2 +10−3 × 9.035θ +1……..1 |
| 3 | Norasteh& Monem (2011) | 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%). |
| 4 | Prakash et al.( 2011) | They developed the head-discharge-inclination model to measure flow over inclined Rectangular weir | angles of inclination are (00, 150, 300 , 450, and 600 ) and actual discharge is from 0.0012 -0.021 m3/s | The results show that the coefficient of discharge increases with an increase in the angle of inclination of the weir  Cd = 0.0005α 2 - 0.0111α + 1.0478…….2  an empirical equation for discharge with water head for different inclination angles is shown in Table below. |
| 5 | Arvanaghi et al.(2014) | a laboratory study to find out the effect of changing the inclination angle of the pivot weir on the coefficient of discharge. | pivot weir angles are (0, 15, 30, and 45°) | using the inclination of the angle for the weir helps to improve the coefficient of discharge. |
| 6 | Nikou et.al.(2016 a) | Estimate Discharge equation to the head for Pivot Weirs with variable Side Contractions | The discharge is between (350-880 l/s). inclination angles (15-50°) | The Head-Discharge Equation is as following:    …..3  …..4  …..5 |
| 7 | Nikou et al. (2016 b) | evaluate the equation for the head–discharge equation over the pivot weir | 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 –174 l/s) | Q = Ct [2 B yu 3/2 ………..6 (})3]…….7  The vertical contraction effects when the angle is greater than 40°, and the coefficient of discharge increases by 44.6% when the angle decreases from 90o to 40°. It is about 61.7% when the weir inclination angle decreases from 40 o to 20°, and ranges from 36.7 to 54.6% when the lateral stenosis increases by 0.4. |
| 8 | Prakash et al.(2018) | Study the angle of inclination on the coefficient of discharge | inclination angles are (0o, 15o , 30o , 45o , 60o ,75o ) | When the inclination angle increased, the discharge coefficient increased    Discharge coefficient with respect to the weir inclination |
| 9 | Azimfar et al.(2018) | evaluating the coefficient of discharge on analytical equations and comparing the results with the denominator obtained experimentally. | angle of the diversion weir is between 16.20 to 900 water depth to weir height is from 0.09 to 1.9 for free and submerge flow types. | Compared to earlier research findings, the results demonstrated that the equations utilized to calculate the discharge coefficient are much simpler and more accurate.      the relationship, under free-flow conditions, between CD exp and CD act MARE for the following weirs: (a) Armtec weir; and (b) USWCL weir. |
| 10 | Mahdavi&Shahkarami (2020) | hydrostatic-corrected smoothed particle hydrodynamics Free Surface Flow Analysis over Pivot Weirs using (SPH) | Inflow discharge between 0.06 to 0.33 m2/s .gate openings are 0.3,0.5 &0.7m.also length of the weir are 0.3,0.4 &0.6m. | SPH demonstrates that by turning on the correction term, a decrease in the reservoir's head is anticipated.        Experimental and numerical results for a-pressure  b-velocity &c-velocity angle |
| 11 | Bijankhan and Ferro (2020) | Submerged Pivot Weir using experimental Modeling | weir heights range from 0.263 to 0.312 meters, while weir inclination angles are 39.6°, 53°, 85°, and 90°.  Tailwater depth's influence downstream of the angled rectangular weir three types of submerged flow: (a) free-flow; (b) wavy; and (c) entirely submerged. | The existing submerged stage-discharge formula greatly overestimated the reported discharge values for the greater submergence situations.  Throughout the whole submergence range, the suggested model can be applied with a mean absolute relative error of 6.4%. |
| 12 | ŞİMŞEK (2020) | NUMERICAL MODELING OF pivot weir | weir inclination angles are (900, 71.60, 56.30, 450, 26.60 & 14.0) | The Reynolds Stress Model produces effective flows with flowlines that have varying angles of curvature. |

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| NO | study | purpose | limitation | results |
| 13 | Sinclair (2021) | They used CFD to compare the sharp-crested and pivot weirs and looked at how the pivot weir's inclination angles affected the discharge coefficient. | five different angles (27°, 47°, 57°, 72°, and 90°) and six different values of the discharge | At an angle of 27o, the discharge coefficient reached its maximum value. |
| 14 | Hajimirzaie  &González-Castro  (2021) | Investigative Simulation of Submerged Pivot Weir | Measured discharge is from 2.45m3/s to 28.3 m3/s | They demonstrated a pivot weir flow rating formula and calibrated it using experimental data.    …..8 |
| 15 | Baratov et.al.  (2021) | management of open canal water levels using modeling and simulation | A pivot weir in open canals  The Matlab tool Simulink is used to construct the mathematical model of the control of water levels in open canals.  . | The dynamic of the water levels control system  The open canal water level control system's requirements are met by the control error of 7%. As a result, the suggested system operates steadily and with a wide margin. |

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| 16 | Khatamipour et al. (2022 a) | Investigations are conducted on the hydraulic conditions of pivot elevator weirs. | Using Ansys CFX software, flow modeling was done to investigate the weir coefficient of discharge. Wahlin and Replogle's experimental data at various angles and discharges were used to assess the model.  The ideal crystal shape was investigated in three different ways: Semicircular, circular, and sharp | The discharge coefficients of weirs with a semicircular crest and an angle of 70o are 0.7 to 7.9% greater than those of weirs with circular sharp-crested weirs, according to the results. For weirs with an angle of 27.80, the increase in discharge coefficient ranged from 0.4 to 3.2%. Therefore, the maximum discharge coefficient values are seen in weirs having semicircular crest edges. |
| 17 | Khatamipour et.al.  (2022 b) | Flow Characteristics Over Pivot Weirs, Numerical Study | Flow discharge 61.5 l/s to 149.6 l/s  Inclination angle 22.40 to 63.40 | They found a relationship as shown:  Ca=0.9364 + 0.0042 θ - 0.00004θ2………………9  Furthermore, the analysis demonstrates that the discharge coefficient rises to 1.076 with an inclination angle.    The relation between Ca & θ |

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| NO | study | purpose | limitation | results |
| 18 | Zerihun  (2022) | Characteristics of discharge and numerical modeling | Empirical equations were created using a non-linear optimization technique for numerical computations. These formulas hold for 26ο ≤θ < 90ο and 0.1≤ h / w < 6.5. | The properties of the curved transcritical flow and the coefficient of discharge are influenced by the relative overflow depth. Additionally, the discharge characteristics of a full-width gate with a face slope flatter than 56° are influenced by the angle of inclination. |
| 19 | 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)    two pivot weir at different inclination angles | 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 side on the left is 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%. |

| NO | study | purpose | limitation | results |
| --- | --- | --- | --- | --- |
| 20 | Pugh et.al.(2023) | CALIBRATION OF THE TILTING WEIR | The angle of inclination is between 250 to 900. The weir vertical height is between 65mm to 150mm. Reynolds number is between 1.6\*102 to 9.6\*104  flow over a weir samples | The head over the weir falls as the inclined angle lowers under a continuous discharge, according to the results, because the flow has a shallower angle of attack. |

**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 axial 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.

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1.

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**List of abbreviations**

|  |  |
| --- | --- |
| B | width of the channel (L) |
| b | width of the weir (L) |
| Ca | the effective coefficient of the angle |
| Cd | coefficient of discharge |
| Ct | discharge coefficient for the second approach |
| G | acceleration due to gravity (L/T2) |
| h, h1 &yu | Depth of water upstream of the weir (L) |
| H | Total energy upstream of the weir (L) |
| L | inclined weir length (L) |
| P & *w* | height of weir (L) |
| Q | discharge (L3/T) |
| y1 | h1+P (L) |
| α & θ | angle of inclination |
| Η | b/B |
| Z | gate opening (L) |

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