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# Experimental Investigation on Discharge Coefficient Changes of Moveable Cylindrical weir-gate

**Armaghan Severi:**
MS. Student of Water structures, Faculty of Agricultural Engineering, Sari Agricultural Sciences and Natural Resources University, Sari, Iran, Email ID : a.severi_1988@yahoo.com

**Mohsen Masoudian**
Assistant Professor, Department of Water engineering, Faculty of Agricultural Engineering, Sari Agricultural Sciences and Natural Resources University, Sari, Iran, Email ID : masoudian@sanru.ac.ir

**Esmaeil Kordi**
Researcher, Aff. Member of ASCE, Email ID : esmaeilkordi@gmail.com

**Klaus Roettcher**
Professor, Faculty of Civil and Environmental Engineering, Ostfalia University of applied sciences, Suderburg, Germany, Email ID : K.roettcher@ostfalia.de

**Abstract - Cylindrical weir- gate structures are one of the combined structures types which have some advantages such as low cost, simple design, ease construction and the high discharge coefficient. In present study free flow hydraulics passing through vertical movable cylindrical structures have been investigated experimentally. The experiments were conducted in rectangular flume with the length of 7.5 m and width of 0.4 m, on flat bed with constant slope 0.0001, by using the PVC pipes with four diameters 50, 75, 110 and 125 mm as cylindrical structures in Civil and Environmental faculty of Ostfalia University of applied sciences hydraulic lab. The experiments were conducted for various gates opening amount from 0 to 60 mm due to vertical movement of the cylindrical structure, with various amount of flow discharge. Experimental results demonstrate that the gate opening changes has inverse relation with discharge coefficient changes, so that by vertical movement of cylindrical structure, the maximum and minimum discharge coefficient amount were observed in cylindrical weir and cylindrical gate respectively. Furthermore, by converting the structure from cylindrical weir- gate to cylindrical gate, the curves depicted amount of discharge coefficient against [$y_{up}/D$] and [$(y_{up}-y_d)/D$] have reduced suddenly, which this progress was due to decreasing the amount of back water and remarkable decreasing in upstream flow depth.**

**Keywords - Cylindrical gate, Cylindrical weir- gate, Cylindrical weir, Discharge coefficient, Simultaneous flow.**

## 1. INTRODUCTION

Due to the relatively simple equations for accurate flow measurement and controlling the water level, weir and gate method is more useful than the separate weir, gate and partial flume methods. Since the flowing water in the channel always contains sediment particles and floating debris, they are deposited at the gate inlets and behind the weirs which reduces the size of the channel in the structure range and will cause some problems such as neighboring land flooding due to overflow of water from the channel banks, threatening the structure stability and reducing the measurement accuracy. Using a combination of weir- gate model, in comparison with other conventional devices, will make it possible to get the actual conditions closer to main hypotheses derived from the relations and accurately measure the discharge coefficient. In this model, the deposited materials are easily passed through the gates and the suspended debris are easily passed over the weirs. One of the combined weir- gate structures is cylindrical weir- gate structure. Regarding the form of the combined weir- gate structures, it has some advantages including easy design, sediments and floating materials flow, high flow discharge coefficient than other replaceable structures and its being economic.

Israelsen and Hanson (1962) showed that when 75 % of weir height is filled with sediment, about 8 % increase occurs in flow discharge [5]. Chanson and Montes (1998) investigated the flow behavior of the cylindrical weir and concluded that the convexity of weir body caused the suction pressure at the surface of the weir and creates the collapse of the blade which causes the stuck of water surface to the body of the weir. Suction on the body and the created blade stuck causes the flow lines and flow to be formed with higher curvature and higher speed, respectively and therefore, discharge coefficient increases towards the rectangular sharp crested and board crested weir [2]. Negm et al, (2002) performed a laboratory test of combined free flow on a contracted rectangular sharp crested weir- gate and indicated that the ratio of [$y_{up}/a$], in which $a$= gate opening amount, and [$P/a$], in which $P$= structure height, have the considerable effect on the discharge coefficient. Furthermore, they resulted that the effect of density and surface tension on passing flow through the combined structure in $P/a$ < 0.5 and $b/a$ < 1 are very significant [6]. Gharahgezlou et al. (2012) conducted a laboratory study of hydraulics of the cylindrical and semi cylindrical weir- gate. The results of the experiments indicate that in every three types of weir- gate structures (cylindrical structure, semi cylindrical structure with upstream curvature and semi cylindrical structure with downstream curvature) by increasing the amount of dimensionless parameters of [$y_{up}/a$] and [$y_{up}/P$] the amount of discharge coefficient increases [3].

Along with the vertical movement of cylindrical structure, the gate opening height changes and three different structures such as weir, weir- gate and gate are observed. As a result, discharge coefficient of combined structure will also change. This structure can be used for precise control and measurement of passing flow in the low water and high water conditions, therefore, in this research, experimental study on effect of vertical movement of cylindrical weir- gate on flow hydraulics was performed.

## 2. Experimental Installation

The experiments were conducted in rectangular and adjustable flume with the length of 7.5 m, width of 40 cm and height of 46 cm, in transparent, glassy flume with 1 cm wall thick and with constant slope 0.0001, in Ostfalia University hydraulic lab. In this research, PVC pipes were used as cylindrical weir- gate structures. The experiments were conducted for four diameters 50, 75, 110 and 125 mm. The ratio of studied diameter to width of flume varied within the range of 0.1 < ($D/B$) < 0.4. Various gate opening heights from a= 0 mm (cylindrical weir) to 60 mm in increments of 10 mm were investigated. Discharge rate covers a range of 12 to 22 lit/sec. Runs were carried out on upstream subcritical flow regime for 0.1 < $Fr_{up}$ < 0.6 and 30000 < $Re_{up}$ < 62000. The discharge was measured by a magnetic flow-meter, with accuracy of ± 0.1 lit/sec, and the water surface level was recorded using a Liminimeter with ± 0.1 mm accuracy. Figure (1) shows definition sketch for a combined flow through a cylindrical weir- gate.

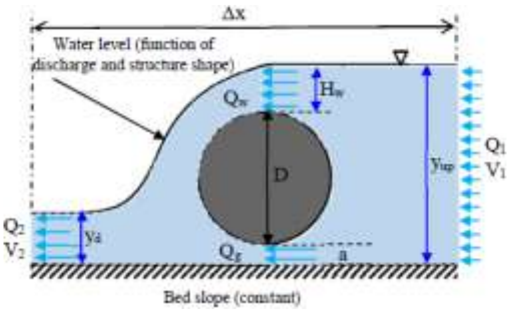


Fig. 1. Schematic diagram of combined over-under flows through a cylindrical weir-gate.

## 3. Theoretical Framework

The total discharge, $Q_s$ was obtained by Eq. (1):

$$Q_s = Q_w + Q_g \qquad (1)$$

Where, $Q_w$= discharge over the weir (m$^3$/s) and $Q_g$= discharge under the gate (m$^3$/s) [6]. Bos (1976) proposed the Eq.(2) for predicting of $Q_w$ for a cylindrical weir [1]:

$$Q_w = C_{dw} B \frac{2}{3} \sqrt{\frac{2}{3} g} H_w^{1.5} \qquad (2)$$

Where, $Q_w$= discharge over the weir (m$^3$/s), $H_w$= head of water over the weir (m), $C_{dw}$= weir discharge coefficient, $B$= rectangular open channel width (m), g= Acceleration of gravity (m/s$^2$). The Eq. (3) was used for estimating of discharge under the cylindrical gate [4].

$$Q_g = C_{dg} a B \sqrt{2 g y_{up}} \qquad (3)$$

Where, $Q_g$= discharge under the gate (m$^3$/s), $C_{dg}$= gate discharge coefficient, $a$= gate opening height (m), $B$= rectangular open channel width (m), $y_{up}$= upstream flow depth (m), g= Acceleration of gravity (m/s$^2$). So, the discharge coefficient $C_{ds}$ can be defined as Eq. (4) [6].

$$C_{ds} = \frac{Q_s}{aB\sqrt{2gy_{up}} + B\frac{2}{3}\sqrt{\frac{2}{3}g} H_w^{1.5}} \qquad (4)$$

Where, $Q_s$= the total discharge (m$^3$/s) and $C_{ds}$= the combined discharge coefficient.

## 4. Results and Analysis

Parameters affecting discharge coefficient of cylindrical combined structure include structure diameter ($D$), gate opening height ($a$), the head of water over the weir ($H_w$), upstream flow depth ($y_{up}$) and downstream flow depth ($y_d$) that, $H_w$, $y_{up}$ and $y_d$ were measured and calculated for each model in different discharges using Eq. (4) coefficient discharge of cylindrical structure and then dimensionless parameters of [$y_{up}/D$] and [$(y_{up}-y_d)/D$] against discharge coefficient in the studied gate opening height for four diameters were investigated.

Figures (2) to (4) show the relation between discharge coefficient with dimensionless parameter of upstream depth ratio to structure diameter in each structure of cylindrical weir to cylindrical weir- gate modes and finally reaching to cylindrical gate with various gate openings for four diameters in the constant discharge. The data are separated into three regions of cylindrical weir, cylindrical weir- gate and cylindrical gate. Furthermore, in a constant diameter and constant discharge, discharge coefficient changes had an increasing process by the decrease of the gate opening height, so that, the highest and lowest discharge coefficient amount were observed in cylindrical weir with range of 1.2< $C_{dw}$ < 1.4 and cylindrical gate with range of 0.4 < $C_{dg}$ < 0.92, respectively. Besides, in a constant discharge and constant gate opening height, discharge coefficient decreases with increase in the structure diameter, and it is argued that flow blade is drawn from over the weir to below the gate with increasing structure diameter that this phenomenon is in the opposite direction of the flow under the gate, thus, causes a positive pressure on the flow passing under the gate and a decrease in the discharge coefficient.

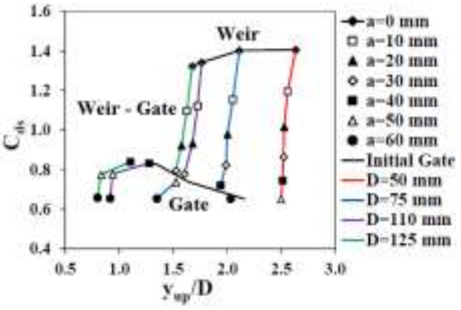


Fig. 2. $C_{ds}$ versus [$y_{up}/D$] for discharge 22 Lit/sec

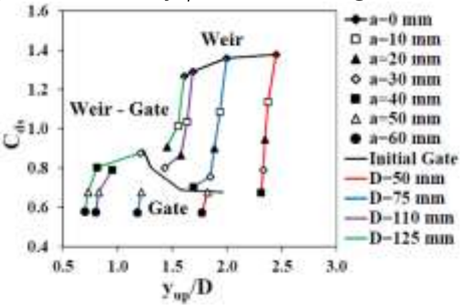


Fig. 3. $C_{ds}$ versus [$y_{up}/D$] for discharge 18 Lit/sec

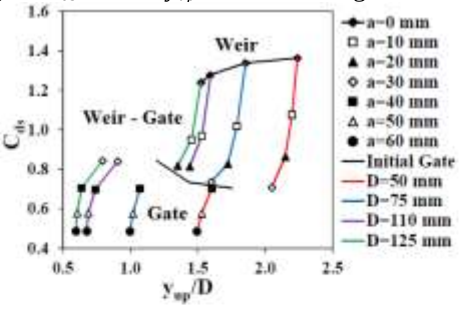


Fig. 4. $C_{ds}$ versus [$y_{up}/D$] for discharge 14 Lit/sec

The figures (5) to (8) show the relation between discharge coefficient with the dimensionless parameter of upstream depth ratio to the structure diameter and figures (9) to (12) show the relation between the discharge coefficient with dimensionless parameter of [$(y_{up}-y_d)/D$] in each structure from cylindrical weir to cylindrical weir- gate modes and finally reaching to the cylindrical gate for various gate openings and discharges in a constant diameter. Figures indicate that, in each of the four studied structure diameters, dimensionless parameters of [$y_{up}/D$] and [$(y_{up}-y_d)/D$] slightly increased with decreasing gate opening height, that this process is as a result of increasing discharge coefficient and reduction of the passing flow capacity which increased back water amount behind the structure and increased upstream flow depth. In constant gate opening height in all diameters of studied cases, dimensionless parameters of [$y_{up}/D$] and [$(y_{up}-y_d)/D$] increased with increasing discharge. Actually, it should be noted that this increasing trend took place in cylindrical weir structure with a less growth rate than cylindrical weir- gate structure and also cylindrical weir- gate structure with a less growth rate than cylindrical gate.

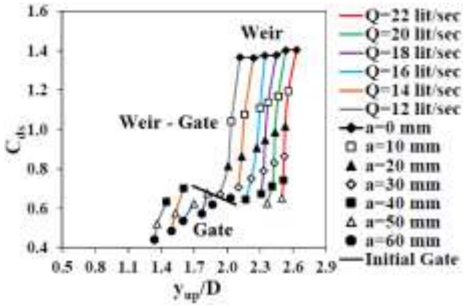


Fig. 5. $C_{ds}$ versus [$y_{up}/D$] for Diameter 50 mm

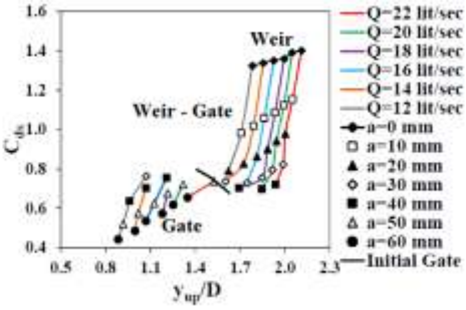


Fig. 6. $C_{ds}$ versus [$y_{up}/D$] for Diameter 75 mm

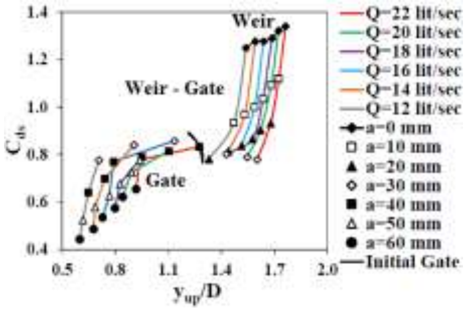


Fig. 7. $C_{ds}$ versus [$y_{up}/D$] for Diameter 110 mm

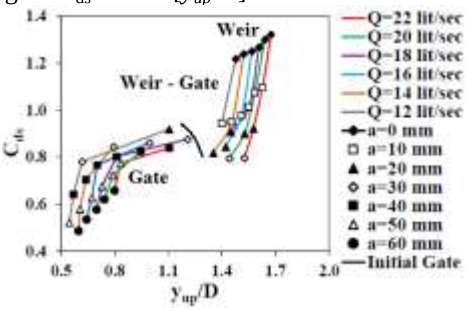


Fig. 8. $C_{ds}$ versus [$y_{up}/D$] for Diameter 125 mm

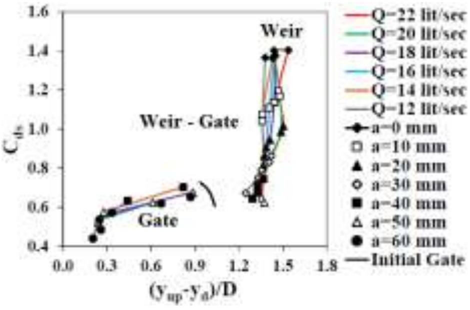


Fig. 9. $C_{ds}$ versus [$(y_{up}-y_d)/D$] for Diameter 50 mm

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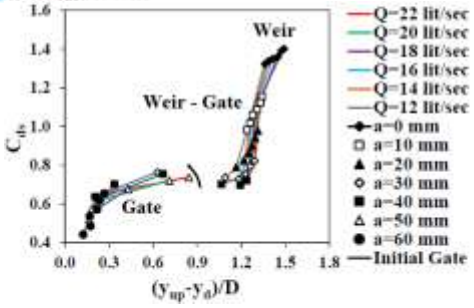

Fig. 10. $C_{ds}$ versus $[(y_{up}-y_d)/D]$ for Diameter 75 mm

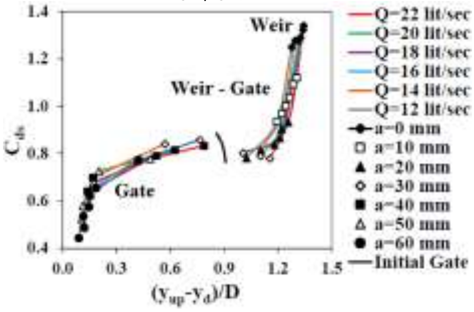

Fig. 11. $C_{ds}$ versus $[(y_{up}-y_d)/D]$ for Diameter 110 mm

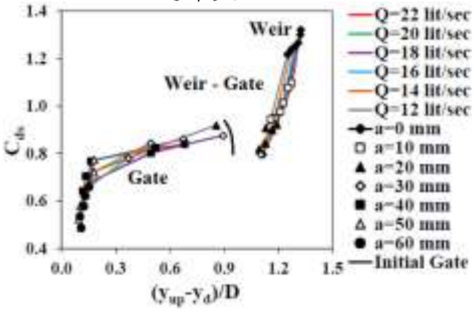

Fig. 12. $C_{ds}$ versus $[(y_{up}-y_d)/D]$ for Diameter 125 mm

Figures (2) and (12) exhibit that in all discharges and all four studied diameters, $C_{ds}$ curves against $[y_{up}/D]$ and $[(y_{up}-y_d)/D]$ shifted to the left side by converting the structure from cylindrical weir- gate to cylindrical gate that this trend is due to the reducing the discharge coefficient, and indicates increasing flow capacity and decreasing required energy loss and thus decreasing back water behind the weir- gate and remarkable decreasing in upstream flow depth.

## 5. Conclusions

The present study results suggest that:

1.The gate opening changes has inverse relation with discharge coefficient changes, so that the maximum and minimum discharge coefficient are visible in cylindrical weir and cylindrical gate, respectively.

2. Amounts of $[y_{up}/D]$ and $[(y_{up}-y_d)/D]$ parameters significantly reduced by converting the structure from cylindrical weir- gate to cylindrical gate that this trend is due to the discharge coefficient reduction which indicates the increase of passing flow capacity and reduction of upstream needed energy loss and thus reduction of back water behind the weir- gate and remarkable decreasing in upstream flow depth.

3. The discharge coefficient changes have direct relation with $[y_{up}/D]$ and $[(y_{up}-y_d)/D]$.

4. Increasing trend of dimensionless parameters of $[y_{up}/D]$ and $[(y_{up}-y_d)/D]$ occurred with discharge increase in the cylindrical weir with less slope than cylindrical gate and it is concluded that since according to the Eq. (3) in the calculation of discharge coefficient, flow depth reach to the power of 0.5 whereas, in the calculation of weir discharge coefficient according to the Eq. (2) it reached to the power of 1.5. Consequently, discharge coefficient variations as a result of upstream flow changes in gate mode was more than weir and the growth rate will also be more.

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