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# Flow Characteristics Over the Weir with Semi-Circular Crest in Normal and Oblique Plane

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***Abstract-*** This paper studies the effect of geometrical characteristics on coefficient of discharge for weirs with semicircular crest in normal and oblique plane as for the purpose of calculating flood discharge passing over the flood embankments. Experimental program consists of four sizes of weirs used at normal plane and at deviation from the wall of channel. Four models comprised of crest height (15 cm, 17.5 cm, 20 cm, 22.5 cm,) with radius of circular crest (6 cm, 8 cm, 10.0 cm, 12.0 cm) respectively. Two angle of inclinations (60°, 30°) were used for experimental setup and 90° angle was used for normal weir for each of the weir size. Results shows that the coefficient of discharge is affected by the geometrical parameters like radius of circular crest, height of crest and angle of inclination. It was noted that larger the radius of circular crest leads to lower the coefficient of discharge for circular crested weir. As well as greater the crest height leads to lower the discharge coefficient ($C_d$). On the other hand the coefficient of discharge for oblique circular crested weir is higher than normal circular crested weir and increases as the inclination with the wall of channel increases.

***Keywords-*** Weir, Discharge coefficient, Oblique weir, Normal weir, Circular crest.

## I. INTRODUCTION

For many centuries engineers have been trying to build a structure across a river to provide required head for proper delivery of water. In any hydraulic structure, means of letting the passage of large quantity water should be provided otherwise the structure is vulnerable to the danger of weakening or collapse due to anticipated or unpredicted floods. A weir structure is an important feature of many hydraulic structures such as dames, barrages, canal drops or falls, regulators, cross regulators, etc. Broad-crested, sharp-crested, the circular-crested weirs and ogee crest weir are the most widely used weirs, these days. The advantages of using the circular crested weir shape are the steady overflow pattern when compared to sharp-crested weirs, passing of floating debris without any difficulty, the simplicity of design compared to ogee crested weir design and the above everything is the lower cost. Circular-crested weirs have more flow efficiency (for indistinguishable upstream head) than both broad-crested and sharp-crested weirs. Inclined weirs do exist in nature in the shape of flood embankments, so their discharge coefficient needs special attention. The novelty of this research is that the study deals with the calculation of discharge coefficient for various new shapes and inclination of weirs as no investigation is done on studying these new weir shapes so far. The discharge coefficient of inclined weirs needs special attention as they are in the shape of flood embankments. By calculating the discharge coefficient of inclined weir the discharge value of flood plain can easily and more precisely be calculated.

## II. LITERATURE REVIEW

The previous study shows that with the increase in inclination, the discharge increases over weir and free flow occurs over the leaned rectangular weirs with angles varying from 0 to 60$^o$ at rate of 15$^o$. They presented an equation which incorporates head, discharge and inclination to estimate discharge [1]. The cylindrical and half-shaped cylindrical weirs and their hydraulic properties shows that the increasing u/s head causes discharge coefficient to increase in case of both weirs. For constant $H_1/R$ value much increase in cylindrical weir's discharge coefficient was noticed as compared to half-shaped cylindrical than that of the half-cylindrical crested weir. Value of upstream head and $C_d$ increased with increasing d/s inclination of weir. Increasing u/s slope had insignificant effect on $C_d$ [2]. The research was conducted to find discharge coefficient ($C_d$) of the cylindrical weir and the research concluded that discharge coefficient ($C_d$) of oblique weir was more than normal weir because oblique weirs provide elongated spans for flow to pass over the weir than normal weir. Irrespective of weir dimensions value of $C_d$ increases with increasing inclination. It was observed that $C_d$ was essentially affected by upstream head over crest. Also, it was found that increase in radius of crest reduced $C_d$ [3]. The effect of u/s and d/s angles on discharge coefficients of circular-crested weirs are studied in detail and the results indicate that varying slope of u/s glacis has insignificant effect on $C_d$. Unlikely, angle of downstream slope had a proportional effect on $C_d$. They suggested a formula for $C_d$ which includes both d/s and u/s face angles. They also studied the tail water submergence of circular-crested weirs [4].This study computed the energy loss and coefficients of discharge for different configurations of trapezoidal weir (for $0^o$, $30^o$, $45^o$ and $60^o$ angle of obliqueness) and flow conditions[5][6]. The hydraulic characteristics of free flow over circular-crested weirs by varying weir height, radius and d/s and u/s slopes. Experimental results were used to formulate a semi-empirical relationship for Cd and velocity distribution over the crest on the basis of free vortex concept which is expressed in terms of circulations. Discharge coefficient estimation was close to experimental values with a margin of +5%.

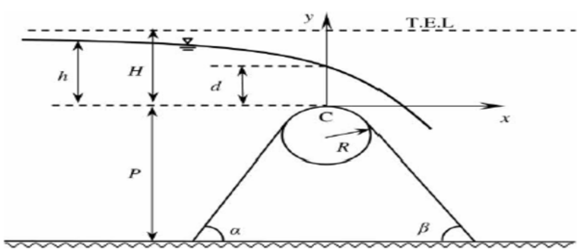



Fig. 1. Flow past circular-crested weir [7]

A one-dimensional curvilinear model under which flow is critical is presented for various conditions. The study established that discharge coefficient increases with normalized specific energy (E/R). It was also concluded that relative depth of flow at crest declines as normalized specific energy increases, if curvature effects are considered [8]. The flow over semicircular crested weirs proposes the velocity profiles and the bottom shear stress numerically [9]. The investigation gives the understanding of pressure distribution over circular and cylindrical crested weirs of varying heights. Increasing the load over weir caused hydrostatic state to exiting conditions of pressure distribution. Also, they found that weir height had insignificant effect on distribution of pressure over weirs, under varying weir height pressure distribution continued to be hydrostatic[10]. By adding fuzzy logic to combination of neural network and guassian membership function and also adding hybrid method to three fuzzy rules cause 1.58% and 5.53% reduction in mean percent error criteria for evaluating Cd of both flat and inclined side weirs. That means neuro-fuzzy approach has more accuracy than other network approaches [11]. The discharge coefficient for circular broad crested weirs was evaluated by using experimental and numerical approaches. Numerical model was compared with experimental results for varying Froude and Reynolds numbers and channel bottom slopes. Suitable matching was shown by results with a 5.13% margin of error [12]. The effects of roughness and diameter sizes of three types of cylindrical weir on passing flow conditions and also reported that $C_d$ and discharge passing over the weir increase with decrease in diameter of cylinder. Increasing roughness size reduce coefficient of discharge. An equation was formulated on the basis of experimental results to correlate flow drainage under different sizes of cylinder and roughness of weir [13]. This study states that by means of the equations of potential flow on rounded planes deliveres a theoretic equation for the calculation of the discharge coefficient ($C_d$) for circular weirs in the situation that H1/HD≥ 2. He deliberated the design HD, the weir head and considered 1.7Rb for it [14]. The flow utility around the cylindrical weir found that the velocity circulation on the crest and a mathematical model is proposed to calculate the discharge coefficient ($C_d$) in rounded crested weirs [15]. The discharge coefficient ($C_d$) to virtual head on circular crested weirs by analyzing the existing data for a d/s angle of $45^o$. He concluded that Cd increases from 0.64 to 1.48 for H/R value ranging from 0.05 to 5.5. But $C_d$ remains the same for H/R value up to 9.5 [16]. Many Studies have analyzed effect of u/s gradient on hydraulic characteristics of weirs with circular crests. They found out that for a constant load, weirs with circular crests have higher discharge efficiency than that of with broad crested and sharp edged. They forwarded relationship to calculate discharge coefficient of circular crested weirs for upstream flow conditions.

$$C_d=1.185\left(\frac{H_w}{R}\right)^{0.136} \qquad 0.45<\frac{H_w}{R}<1.9$$

Where $H_w$ indicates total load over weir's crest and R indicates the radius of weir's crest [17]. A model is devised to estimate Cd for sharp crested and circular crested weirs if effect of surface tension is included [18]. The study was conducted on upstream (u/s) and downstream (d/s) phase slope change influence on the coefficient of discharge ($C_d$) for circular crested weir and it was observed that the changes in upstream (u/s) slope will not influence on the coefficient of discharge but increasing downstream inclination angle will increase the coefficient of discharge [19]. The experimental flow over normal weirs with semicircular and crescent shaped crests is studied and it is concluded that the coefficient of discharge ($C_{d)}$ values for both crescent and semicircular shaped crests were very close [20]. The potential flow theory around a circular cylinder with circulation, an analytical model was derived to predict the velocity distribution and discharge coefficient of circular-crested weirs [21]. The elimination of separation zone is the primary source of energy loss, discharge coefficient for quarter-circular crested weir is significantly larger than for finite crest length weir [22].

The more accurate results can be achieved by using noncomplex formulas for semi-circular weirs with sharp and semi-circular crests [23]. An experimental study was conducted on the hydraulic characteristics of arced weirs located in a reservoir. The accuracy and ability was validated for arced weir using experimental data of the response surface methodology, especially central composite design to describe the hydraulic performance of this type of weir [24].

## III. METHODOLOGY

*A. Laboratory Channel and Circular Crested Weir*

Laboratory experiments were performed in the Hydraulics Laboratory of Civil Engineering Department University of Engineering and Technology Taxila, where the Channel used is 96 cm wide, 75 cm deep and 20 m long. The channel with glass side walls and concrete bottom is used for experimental purpose. The channel takes water from a side tank through pump and discharges water into the stilling tank, when the stilling tank gets filled with water, it overflows in the main channel, Fig (2). The flow of water in the channel is computed by using rectangular trapezoidal weir provided at the end of channel. The water level is measured by point gauge installed within the channel. In research laboratory, circular crested weirs were used with various crest height and radius, made of wood and placed consecutively inclined and normal to the channel wall, Fig (3). The wooden weirs were installed at 5 m distance from the channel entering point. The details of weirs model is listed in Table (I).

TABLE I MODEL DETAILS

| Group No. | Oblique Angle(β) | Crest Radius R(cm) | Crest Length L(cm) | Crest Height P(cm) |
|---|---|---|---|---|
| $G_{11}$ | 90° (normal weir) | 6.0 | 96.0 | 15.0 |
| $G_{12}$ | | 8.0 | 96.0 | 17.5 |
| $G_{13}$ | | 10 | 96.0 | 20.0 |
| $G_{14}$ | | 12 | 96.0 | 22.5 |
| $G_{21}$ | 60° | 6.0 | 111 | 15.0 |
| $G_{22}$ | | 8.0 | 111 | 17.5 |
| $G_{23}$ | | 10 | 111 | 20.0 |
| $G_{24}$ | | 12 | 111 | 22.5 |
| $G_{31}$ | 30° | 6.0 | 192 | 15.0 |
| $G_{32}$ | | 8.0 | 192 | 17.5 |
| $G_{33}$ | | 10 | 192 | 20.0 |
| $G_{34}$ | | 12 | 192 | 22.5 |

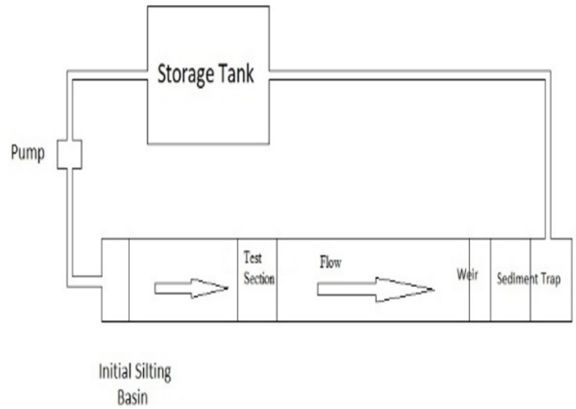



Fig. 2. Top View of Laboratory channel

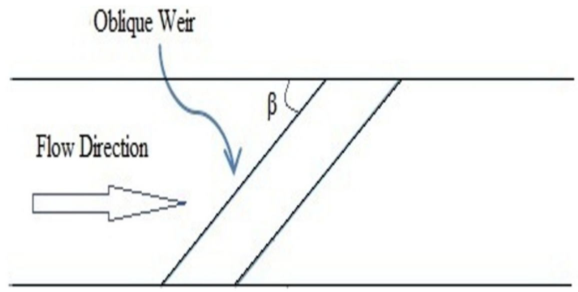



Fig. 3. Top View of Oblique Weir and Angle of its Inclination

*B. Discharge Measurement*

A weir is installed at the end of the channel to measure the discharge quantities. The Compound weir consist of rectangular and trapezoidal sections having sharp edges at crest of weir is used. CRTSC weir is designed on the specification provided by ASCE.

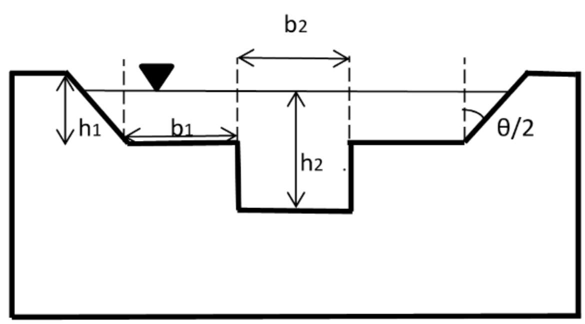



Fig. 4. Schematic diagram of weir

The values of discharges are calculated with the help of CRTSC equation. [25]

$$Q= \frac{2}{3}\ C_{rd2}\sqrt{2g}\ \ b_2 h_2^{3/2}\ +\ \frac{2}{3}\ C_{rd1}\sqrt{2g}\ \ (2b_1)h_1^{3/2}\ + \frac{8}{15}C_{td}\sqrt{2g}\tan(\theta/2)\ h_{1e}^{5/2} \quad (1)$$

Where b = weir length

$C_{rd}$= coefficient of discharge of the rectangular sharp-crested weir.

$C_{td}$= coefficient of discharge for triangular sharp-crested weir.

g = gravitational acceleration
h = water head on the weir crest
$h_e$= effective head
θ = notch angle

$$C_{rd}=\frac{0.611+2.23(\frac{B}{b}-1)^{0.7}}{1+3.8(\frac{B}{b}-1)^{0.7}}+\frac{0.075+0.011(\frac{B}{b}-1)^{1.46}}{1+4.8(\frac{B}{b}-1)^{1.46}}\frac{h}{P} \quad (2)$$

The discharge coefficient $C_{rd}$ values would depend on the channel width B, weir length b, head on the crest h and weir height P. [26]

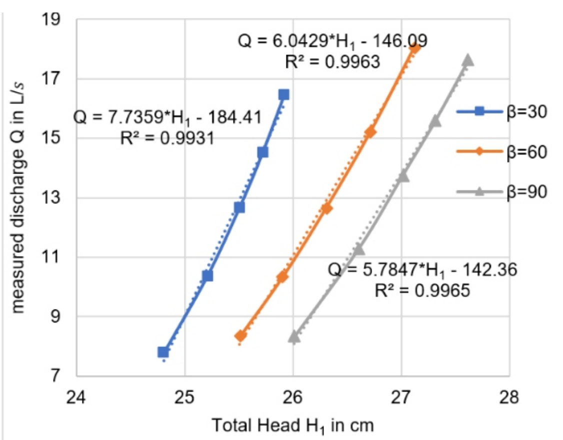
$$h_e = h + K_h \quad (3)$$

$K_h$= correction head. The value of $K_h$ in mm. Correction head factor accounts for viscous forces and surface tension effects. [16]

$$K_h= 3.9058-3.8558\theta + 1.1940\theta^2 \quad (4)$$
$$C_{td} = 0.6085-0.0525\theta+0.02135\theta^2 \quad (5)$$

*C. Experimental work Calculations*

The experiments on circular crested weirs were performed by dividing it in three different groups. Four weir sizes were used in first group with weir dimension of 22.5 cm, 20.0 cm, 17.5 cm, and 15.0 cm placed at (90°) angle with wall of channel. While the same dimensions were used for both second and third groups with angle position at (60°, 30°) angles (oblique weir) respectively. It had been used (60) discharge by five runs for each of the twelve models. Through these experiments, the water depth data above the composite rectangular-trapezoidal weir (h) was taken to calculate the discharge of the equation (1) and the depth of water upstream for the circular crested weir.




(a)

under study (in the case of vertical and oblique weirs) ($d_1$) was noted to find the coefficient of discharge.

The value of ($H_1$), which represents the total head as:

$$H_1=d_1+\frac{q_w{}^2}{2*g*d_1{}^2} \quad (6)$$

Where $d_1$ is depth of water upstream the circular crested weir.

The value of total head above the weir crest ($H_w$) was calculated using the following equation:

$$H_w= H_1 - P \quad (7)$$

Where: P is crest height.

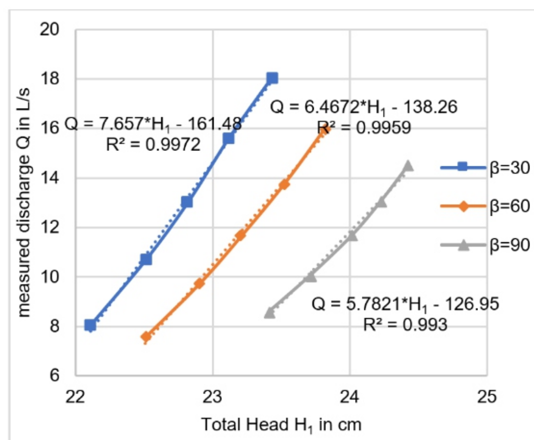
The value of coefficient of discharge of circular crested weir ($C_d$) is calculated using the following equation [xxvii]:

$$q_w=C_d*\frac{2}{3}*\sqrt{\frac{2}{3}*g}*H_w{}^{1.5} \quad (8)$$

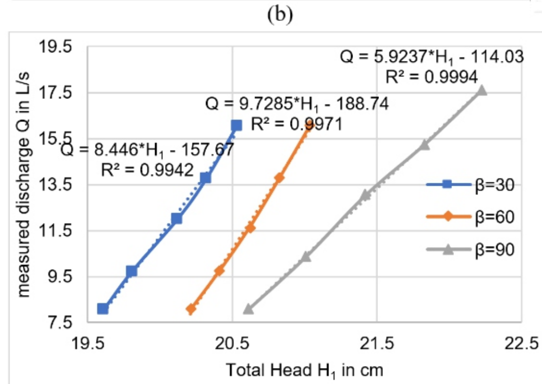
## IV. RESULTS AND DISCUSSION

*A. Relation between upstream head and measured discharge*

The discharge values from the experiments of the three angles and four crest heights of circular crested weirs are plotted against the upstream head in figure (4). It was noted that discharge passing over the weir increases with increase in upstream head. The discharge was measured between 6-18 L/s for whole experimental programme.




(b)

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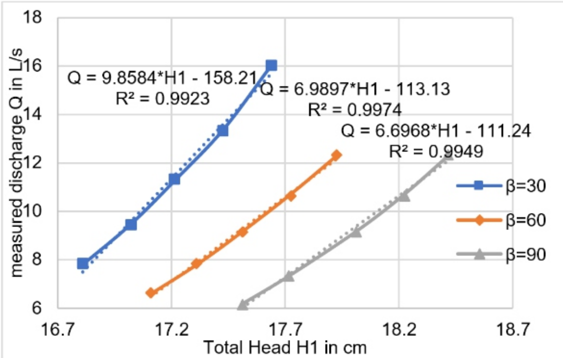


(d)

Fig. 4. Relation among upstream head and discharge for (a) P = 22.5 cm, (b) P = 20 cm, P = 17.5 cm, (d) P = 15 cm

*B. Effect of Upstream Head on Discharge Coefficient*

The values of discharge coefficient ($C_d$) are plotted against the head to crest ratio ($H_w/P$) as shown in figure (5). This figure show that ($C_d$) increases as head to crest ratio ($H_w/P$) increases and it was observed that coefficient of discharge is significantly affected by the upstream head over the crest ($H_w$), where ($C_d$) values goes on increasing with increasing ($H_w$). It's seeming at very small values of ($H_w$), the influence of viscosity and surface tension can disturb the performance and outcomes in curves displayed.

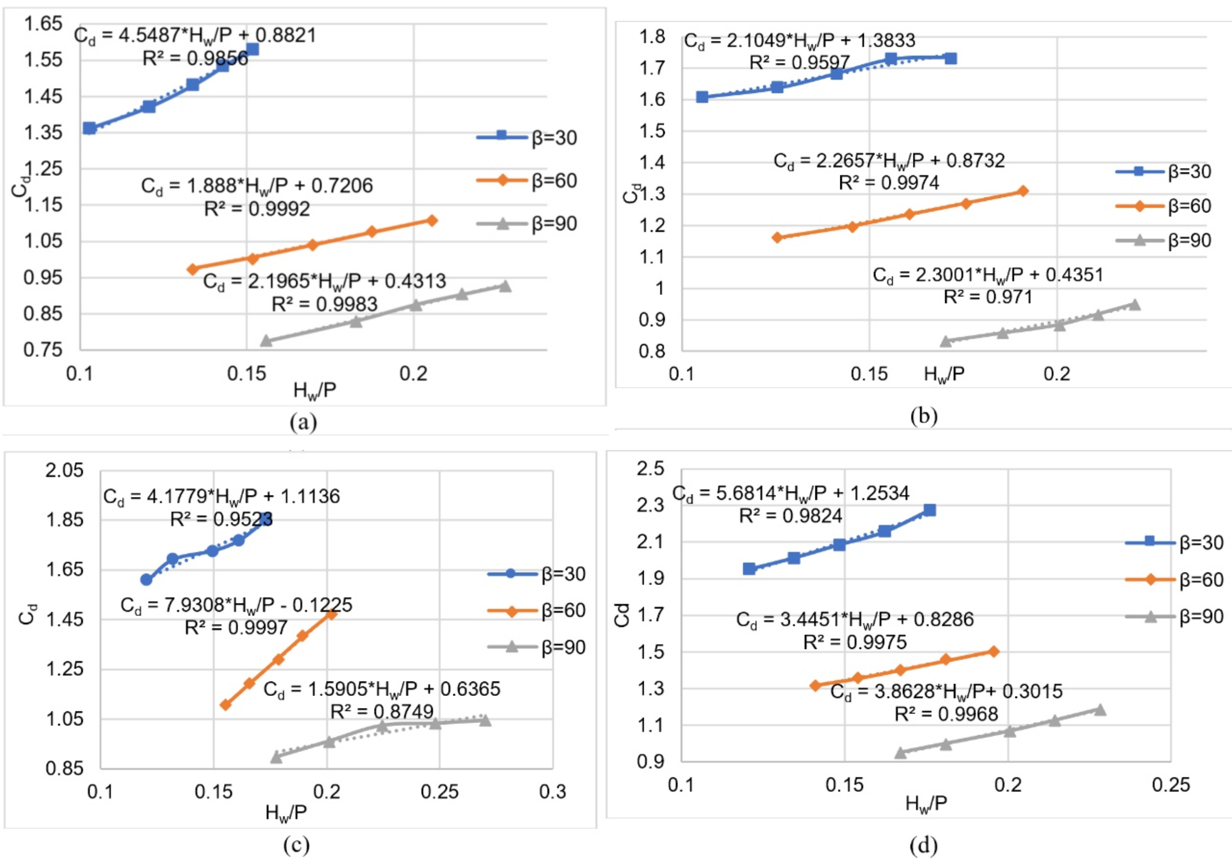


Fig. 5. Relationship between discharge coefficient ($C_d$) and the dimensionless value ($H_w/P$) for weir of crest height (a) P = 22.5 cm, (b) P = 20 cm, (c) P = 17.5 cm, (d) P = 15 cm.

*C. Effect of Crest height of the weir on Discharge Coefficient:*

The effect of crest height of weir was examined over runs of experimentations. The average discharge coefficient for all models is plotted against crest height of weir at each angle of inclination as shown in the figure (6). Which indicates that the discharge coefficient reduced as the crest height of weir increased at each angle of inclination. And it was noticed that the maximum value of discharge coefficient was recorded against minimum crest height. The influence of curvature is to yield significant acceleration mechanisms or centrifugal forces perpendicular to the direction of flow. It seems that if the flow lines are rounded there is a substantial flow velocity lead to rise the coefficient of discharge.

*D. Effect of Radius of crest on Discharge Coefficient*

The discharge coefficient statistics ($C_d$) are plotted against the head to radius of crest ($H_w/R$) as demonstrated in figure (7). This figure show that (Cd) increases as head to radius of crest ($H_w/R$) increases. Also it was observed that coefficient of discharge is significantly affected by the radius of crest. Where ($C_d$) values are less in case of greater values of radius of crest.

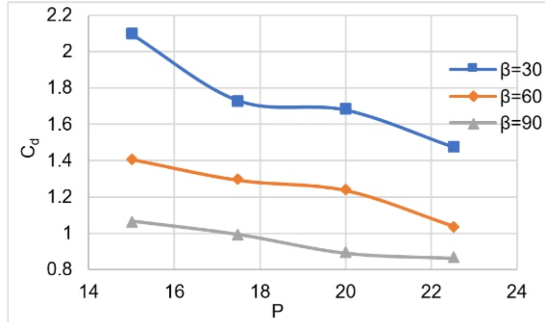


Fig. 6. Relationship between average discharge coefficient ($C_d$) and the crest height of circular crested weir (P).

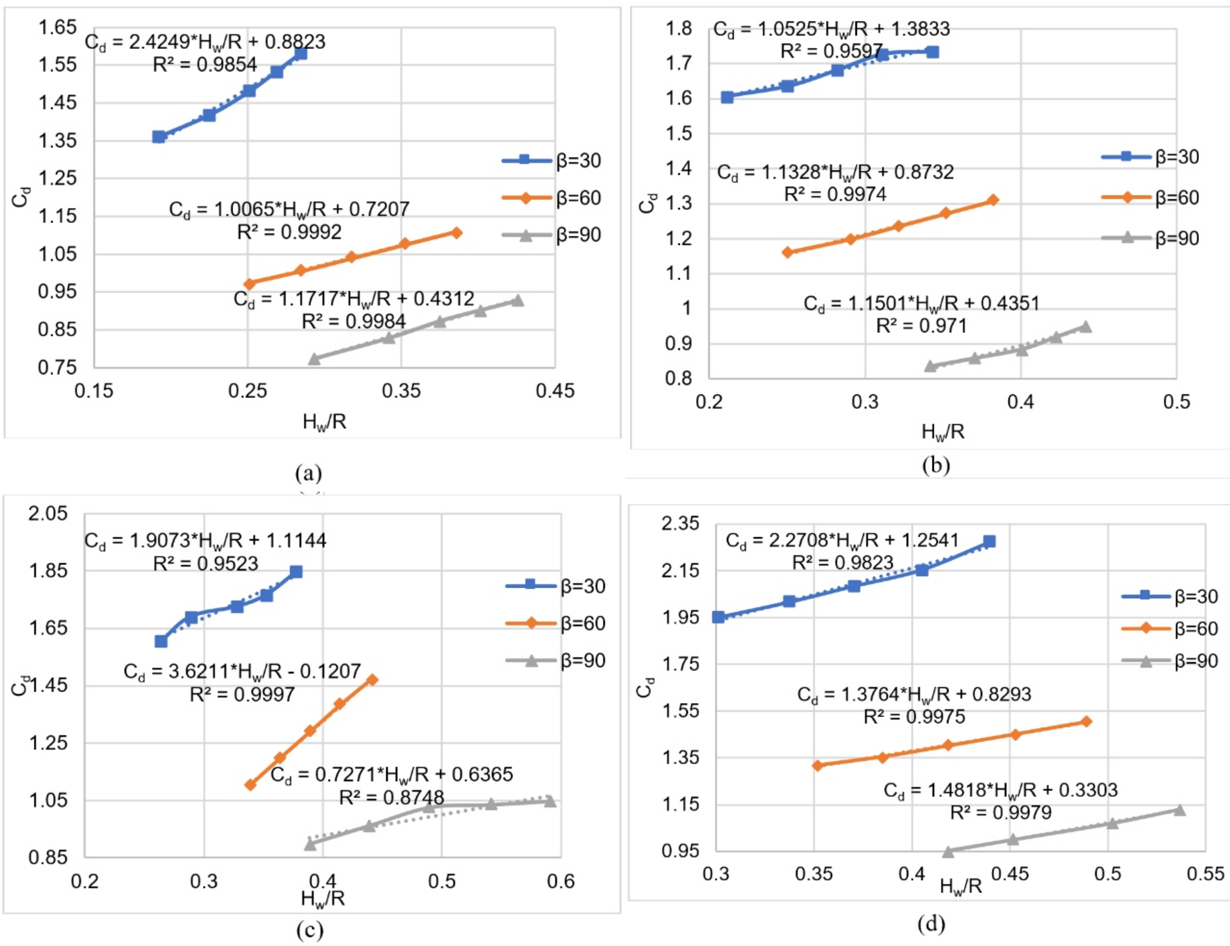


Fig. 7. Relationship between discharge coefficient ($C_d$) and the dimensionless value ($H_w/R$) for weir of crest height (a) P = 22.5 cm, (b) P = 20 cm, (c) P = 17.5 cm, (d) P = 15cm.

*E. Effect of weir inclination on Discharge Coefficient*

The relationship between the inclination of the weir (β) with channel wall and average discharge coefficient ($C_d$) was plotted as shown in figure (8). It was noted that the average discharge coefficient ($C_d$) increases as inclination of weir increases with wall of the channel. This means that the oblique weir has more value of ($C_d$) than the normal weir. Weir of angle of deviation with wall of the channel (β) = 30° give more values of ($C_d$) than those of 60° and 90° because weirs of lesser oblique angle give elongated spans for flow to pass over them.

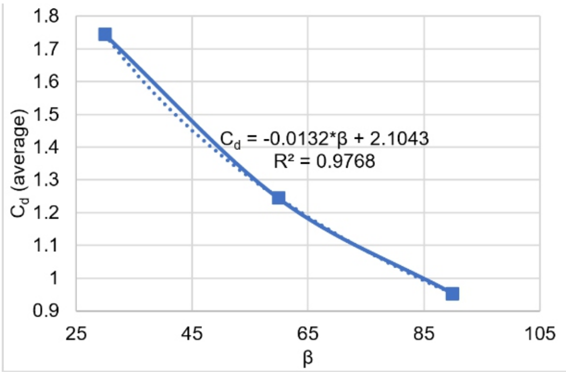


Fig. 8. Relationship between average discharge coefficient ($C_d$) and the angle of inclination (β) of circular crested weir.

## V. Conclusion

This paper characterizes the study of flow features over oblique circular crested weir associated with normal circular crested weir. The results shows that the oblique circular crested weir has more value of coefficient of discharge than normal circular crested weir (as from the fig.8 average $C_d$ = 1.74 for β = 30° which is greater than average $C_d$ = 0.95 for β = 90°) because Oblique circular crested weirs provide longer length for flow to pass over them than the normal circular crested weir. As well as the more is the inclination with channel wall more is the coefficient of discharge value irrespective of weir dimension.

From the results shown we can conclude that discharge coefficient ($C_d$) is significantly affected by the upstream head over the crest ($H_w$). As well as the results shows that the coefficient of discharge is affected by the geometrical considerations like radius of circular crest and height of crest. It was noted that larger the radius of circular crest leads to lower the coefficient of discharge for circular crested weir. As well as greater the crest height leads to lower the coefficient of discharge ($C_d$).

## Notation

$d_1$= depth of water upstream of circular crested weir
$H_1$= total head upstream circular crested weir
$H_w$= total head above the crest
P = crest height of circular crested weir
$q_w$= discharge per unit width
R = radius of circular crested weir
$C_d$= discharge coefficient
β = Inclination angle

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