Behavior of the Discharge Coefficient for the Overflow Characteristics of Oblique Circular Weirs

Emad Abdul Gabbar Al Babely
Ass. Lecturer
Technical College - Mosul

Abstract

This paper presents an experimental study and analysis for effect of the geometrical characteristics, of the oblique cylindrical weir on discharge coefficient, wherefrom three sizes used for the weir and two angles for the deviation.

From the results, it was found that the coefficient of discharge is affected by geometrical characteristics represented by radius of the weir and the angle of inclination with the wall of the channel. It was noticed that the increase in the radius of the weir lead to a low discharge coefficient of the cylindrical weir. And found that discharge coefficient of the oblique weir is higher than the discharge coefficient of the normal weir. And the value of discharge coefficient is directly proportional with the weir inclination.

Keywords: Discharge coefficient, Oblique cylindrical weir, Overflow characteristics.

سلوك معامل التصريف لخصائص الجريان أعلى الهدارات الاسطوانية المائلة

الخلاصة

يقدم هذا البحث دراسة عملية وتحليل لتأثير الخصائص الهندسية للهدار الاسطواني المائل على معامل التصريف، حيث استخدم ثلاث احجام مختلفة للهدار الاسطواني وزاويتين مختلفتين للانحراف.

من النتائج تم التوصل الى ان معامل التصريف يتأثر بالخصائص الهندسية للهدار الاسطواني المتمثلة بنصف قطر الهدار وزاوية ميل الهدار مع جدار القناة. فقد لوحظ ان زيادة نصف قطر الهدار تؤدي إلى انخفاض معامل التصريف للهدار الاسطواني. ووجد أن معامل التصريف للهدار المائل أكبر منه للهدار العمودي. وأن قيمة معامل التصريف تتناسب طرديا مع ميل الهدار.

الكلمات الدالة: معامل التصريف، الهدار الاسطواني المنحرف، خصائص الجريان.

Notations

The following symbols are used in this paper:

b ------ channel width (L).

C_d----- discharge coefficient of circular weir.

$C_{d(weir)}$ discharge coefficient of rectangle sharp crested weir.

d_1 ----- flow depth upstream the weir (L).

D ----- weir diameter (L)

g ------ gravity constant (L/T^2).

h_1 ----- height of cylindrical weir (L).

h ------height of the water upstream rectangle sharp crested weir (L).

H_w ---- energy head over weir crest (L).

H_1 ----- total head upstream of the weir (L).

p------- height of rectangle sharp crested weir (L).

P ------ Height of weir above channel bed (L).
q_w -----Water discharge per unit width (L^2T).
R ------ Radius of the weir (L).
ρ ------ Mass density of water (M)
μ---- Dynamic viscosity of water (M/LT)

Introduction

Optimal use of land and water resources is an important task in dry regions. In developing countries the management and maintenance of many irrigation projects have problems due to economic and technical deficiencies. Thus, the agricultural yield and the farmer's income may not be adequate in those regions. Better water distribution in agricultural lands, necessitates improvement of management in irrigation and drainage canals and related hydraulic structures.

Weirs are among the most popular and simple hydraulic structures, which can be used for various purposes, such as flow measurement and diversion, energy dissipation to regulate the flow depth. Weirs can be constructed in various types and shapes, normal or oblique to the flow direction related to the efficiency [1].

Circular weirs can be classified as "Short Crested Weirs" and passes characteristics of both the broad-crested weirs and sharp-crested weirs. Over their crest surface, the streamlines are highly curved and the pressure across the flow nape strongly deviates from hydrostatic conditions. The circular-crested weir is commonly used to measure and control open channel flow.

Probably the first rational approach to studying flow over oblique weirs was published by De Vries in his report in Dutch (1959). The main objective of the research was to examine the influence of the obliqueness of the weir to the flow. Experiments were done on trapezoidal weirs [2].

In (1988), Ibraheem, et al.[3] studied the performance of oblique sharp crested weirs for different angles (45, 30, and 15) with constant weir height (P = 10 cm). They suggest some equations for the performance of oblique weirs.

In (1996), Chilmeran[4] Studied the flow characteristics upstream the normal and oblique semi-circular crested weirs. He used 48 models with different heights, radii, and angles of the weir and he showed that the discharge coefficient in the case of normal weir increases with the increase of the ratio (h_1/P), while in the case of oblique weir, the discharge coefficient decreases with the increase of the ratio (h_1/P).

More recently, Al-Moula (2004)[5] investigate the effect of downstream face slope of normal and oblique weirs with semicircular crests on the characteristics of flow under free over flow conditions. His experimental results show that the discharge coefficient (C_d) of normal weirs increases with the increase of head to crest height ratio (H_w/P), and for oblique weirs, it was found that (C_d) decreases with increase of (H_w/P) values.

This paper provides a fresh look for describing the behavior of the discharge coefficients for the flow over normal and oblique circular weirs.

Laboratory Channel and cylindrical weir

Laboratory experiments were performed in the Hydraulics Laboratory of Mosul Technical Institute / Department of water resources techniques, where the Channel used is (20 cm) width and (25 cm) height and (4 m) length. The channel bottom is made of aluminum and side walls made of glass. The channel provides with water from a tank beside the channel through pump discharges water into the stilling tank then to the channel. The channel contains crows to control the channel slope, Fig. (1). The channel provided with suppressed rectangular sharp crested weir at the end to calculate the channel discharge. The Channel contains Point gage to measure water level.

In laboratory, cylindrical Weirs were used with different diameters, made from plastic and placed with different angles with channel wall, Fig (2). The weirs were putted at a distance (2 m) from the channel entrance. In all tests the weirs did not expose to atmosphere (ventilation).

Evaluation of Discharge

To obtain the channel discharge in each experiment, the channel provided with rectangular suppressed weir putted at the end of the channel with height of (10 cm) where The discharge per unit width of a Circular weir across a rectangular channel (q_w) can be determined by application of the Rehbook formula[6].

$$q_w = C_d * \frac{2}{3} * \sqrt{2g} * h^{3/2} \quad \ldots\ldots\ldots\ldots\ldots \textbf{(1)}$$

$$C_{d(weir)} = 0.602 + 0.083 * \frac{h}{p} \quad \ldots\ldots\ldots \textbf{(2)}$$

Where:

q_w = discharge per unit width of the channel ($m^3/s/m$).

$C_{d(weir)}$ = discharge coefficient of rectangle sharp crested weir.

g = ground acceleration.

p = height of rectangle sharp crested weir (m).

h = height of the water upstream rectangle sharp crested weir (m).

Dimensional analysis

The variables that depend on characteristics of flow over normal and oblique cylindrical weirs are much. Including the geometry, the shape of the weir, the Radius of the weir (R), and the angle of inclination of the weir with the channel wall (β). Followed by the flow characteristics such as the ground acceleration (g), discharge passing over the weir per unit width of the channel (q_w), and the energy head over weir crest (H_w). The fluid properties are mass density (ρ) and dynamic viscosity (μ). Therefore, the discharge flowing over the vertical and oblique weir per each unit width of channel is a function of variables mentioned above (Streeter, 1983).

$$f(q, H_w, R, g, \rho, \mu, \beta) = 0 \quad \ldots\ldots\ldots\ldots \textbf{(3)}$$

From the variables mentioned above, it can be inferred numbers of dimensionless values (H_w/R, β) which represent the conditions of flow by using the theory of (π's-Theorem)[7].

Experimental work Calculations

The experiments on cylindrical weir were performed by separated it with three groups. In the first group it was used three sizes of weirs (11 cm, 9 cm, 6.35 cm) and (90^o) angle (normal weir) with channel wall. The second and third groups include the use of the same diameter sizes used in the first group with (45^o, 30^o) angles (oblique weir) respectively, Fig. (3).

It has been used (45) discharge by five runs for each of the nine models. Through these experiences, the data of water depth above the standard rectangular sharp crested weir (h) were taken to calculate the discharge of the equation (1) and the depth of water upstream the circular weir under study (in the case of vertical and oblique weirs) (d_1). Tables (1) to (3) shows all of these data.

The value of (H_1), which represents the total head, was calculated using the following equation:

$$H_1 = d_1 + \frac{q_w^{\ 2}}{2 * g * d_1^{\ 2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where d_1 is depth of water upstream the circular weir.

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

$$H_w = H_1 - D \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Where: D is weir diameter.

The value of discharge coefficient of cylindrical weir (C_d) is calculated using the following equation[8].

$$q_w = C_d * \frac{2}{3} * \sqrt{\frac{2}{3} * g * H_w^{\ 1.5}} \quad \ldots. (6)$$

Effect of Upstream Head on Discharge Coefficient

The discharge coefficient data (C_d) are plotted as function of the ratio (H_w/R) as illustrated in figures (4 - 6). These figures show that (C_d) is proportional to (H_w/R). also it was noticed that (C_d) is greatly affected by the upstream head over the crest (H_w). Where (C_d) values increase with increasing (H_w). It's apparent at very low values of (H_w), the effect of surface tension and viscosity would influence the behavior and results in curves shown.

Effect of Diameter of weir on Discharge Coefficient

The effect of diameter of weir was investigated through series of experiments as shown in tables (1-3). The average discharge coefficient for each model is plotted versus diameter of weir as shown in the figure (7). Which shows that the discharge coefficient decreased as the diameter of weir increased? The effect of curvature is to produce appreciable acceleration components or centrifugal forces normal to the direction of flow. It appears that if the stream lines are curved there is a significant flow velocity lead to increase the discharge coefficient [9].

Effect of weir inclination on Discharge Coefficient

The relationship between the average discharge coefficient (C_d) and the inclination of the weir with channel wall (β) was plotted as shown in figure (8). It was noticed that the average (C_d) inversely proportional to (β). This means that the oblique weir has higher (C_d) than the vertical weir. Weir of oblique angle (β) = 30° give higher values of (C_d) than those of 45° and 90° because weirs of small oblique angle give longer lengths for flow to pass over.

Conclusions

This paper represents the study of flow characteristics over oblique cylindrical weir compared with normal weir. The results show that the oblique weir is more efficient than the normal one because oblique weirs give longer lengths for flow to pass over than the normal one. As well as the increase in the inclination angle leads to increase in the discharge coefficient values regardless of weir size.

Also, the study shows that (C_d) is greatly affected by the upstream head over the crest (H_w). It was found that the discharge coefficient affected by geometric characteristics represented by radius of weir, where (C_d) decreased as the radius of weir increased.

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Table (1) Experimental and Calculated Data for Normal Cylindrical Weir.

D (cm)	h (m)	C_d (weir)	q_w ($m^3/s/m$)	d_1 (cm)	H_1 (m)	H_w	H_w/R	Cd	Ave. (C_d)
11	0.03	0.627	0.0096	14.20	0.1422	0.0322	0.586	0.975	1.032
11	0.032	0.629	0.0106	14.37	0.1440	0.0340	0.618	0.995	
11	0.034	0.630	0.0117	14.52	0.1455	0.0355	0.646	1.022	
11	0.036	0.632	0.0127	14.65	0.1469	0.0369	0.671	1.055	
11	0.039	0.634	0.0144	14.82	0.1487	0.0387	0.703	1.112	
9	0.031	0.628	0.0101	11.86	0.1190	0.0290	0.644	1.203	1.215
9	0.034	0.630	0.0117	12.13	0.1218	0.0318	0.706	1.208	
9	0.037	0.633	0.0133	12.40	0.1246	0.0346	0.769	1.213	
9	0.039	0.634	0.0144	12.58	0.1265	0.0365	0.810	1.215	
9	0.044	0.639	0.0174	13.00	0.1309	0.0409	0.909	1.233	
6.35	0.0315	0.628	0.0104	9.25	0.0931	0.0296	0.934	1.192	1.229
6.35	0.035	0.631	0.0122	9.54	0.0962	0.0327	1.031	1.208	
6.35	0.037	0.633	0.0133	9.70	0.0980	0.0345	1.085	1.219	
6.35	0.039	0.634	0.0144	9.85	0.0996	0.0361	1.137	1.234	
6.35	0.042	0.637	0.0162	10.00	0.1013	0.0378	1.192	1.290	

Table (2) Experimental and Calculated Data for Oblique Cylindrical Weir with 45^o Inclination.

D (cm)	h (m)	C_d (weir)	q_w ($m^3/s/m$)	d_1 (cm)	H_1 (m)	H_w	H_w/R	C_d	Ave. (C_d)
11	0.029	0.626	0.0091	13.76	0.1378	0.0278	0.506	1.154	1.224
11	0.03	0.627	0.0096	13.80	0.1382	0.0282	0.514	1.188	
11	0.034	0.630	0.0117	14.10	0.1413	0.0313	0.570	1.233	
11	0.038	0.634	0.0139	14.40	0.1445	0.0345	0.627	1.270	
11	0.039	0.634	0.0144	14.48	0.1453	0.0353	0.642	1.276	
9	0.0285	0.626	0.0089	11.30	0.1133	0.0233	0.518	1.465	1.507
9	0.031	0.628	0.0101	11.48	0.1152	0.0252	0.560	1.484	
9	0.033	0.629	0.0111	11.60	0.1165	0.0265	0.588	1.517	
9	0.0345	0.631	0.0119	11.70	0.1175	0.0275	0.612	1.532	
9	0.036	0.632	0.0127	11.81	0.1187	0.0287	0.638	1.538	
6.35	0.0302	0.627	0.0097	8.80	0.0886	0.0251	0.791	1.432	1.499
6.35	0.032	0.629	0.0106	8.90	0.0897	0.0262	0.826	1.467	
6.35	0.034	0.630	0.0117	9.00	0.0909	0.0274	0.862	1.512	
6.35	0.036	0.632	0.0127	9.15	0.0925	0.0290	0.913	1.515	
6.35	0.039	0.634	0.0144	9.30	0.0942	0.0307	0.968	1.571	

Table (3) Experimental and Calculated Data for Oblique Cylindrical Weir with 30° Inclination.

D (cm)	h (m)	C_d (weir)	q_w ($m^3/s/m$)	d_1 (cm)	H_1 (m)	Hw	H_w/R	C_d	Ave. (C_d)
11	0.03	0.627	0.0096	13.43	0.1346	0.0246	0.447	1.466	1.508
11	0.031	0.628	0.0101	13.50	0.1353	0.0253	0.460	1.476	
11	0.0335	0.630	0.0114	13.65	0.1369	0.0269	0.488	1.520	
11	0.0355	0.631	0.0125	13.80	0.1384	0.0284	0.517	1.527	
11	0.04	0.635	0.0150	14.12	0.1418	0.0318	0.578	1.554	
9	0.029	0.626	0.0091	11.10	0.1113	0.0213	0.474	1.717	1.753
9	0.0327	0.629	0.0110	11.35	0.1140	0.0240	0.533	1.736	
9	0.0351	0.631	0.0123	11.52	0.1158	0.0258	0.573	1.737	
9	0.037	0.633	0.0133	11.63	0.1170	0.0270	0.599	1.761	
9	0.041	0.636	0.0156	11.85	0.1194	0.0294	0.653	1.816	
6.35	0.0302	0.627	0.0097	8.45	0.0852	0.0217	0.683	1.786	1.809
6.35	0.033	0.629	0.0111	8.62	0.0871	0.0236	0.742	1.808	
6.35	0.035	0.631	0.0122	8.75	0.0885	0.0250	0.787	1.812	
6.35	0.037	0.633	0.0133	8.88	0.0899	0.0264	0.833	1.814	
6.35	0.0415	0.636	0.0159	9.16	0.0931	0.0296	0.933	1.827	

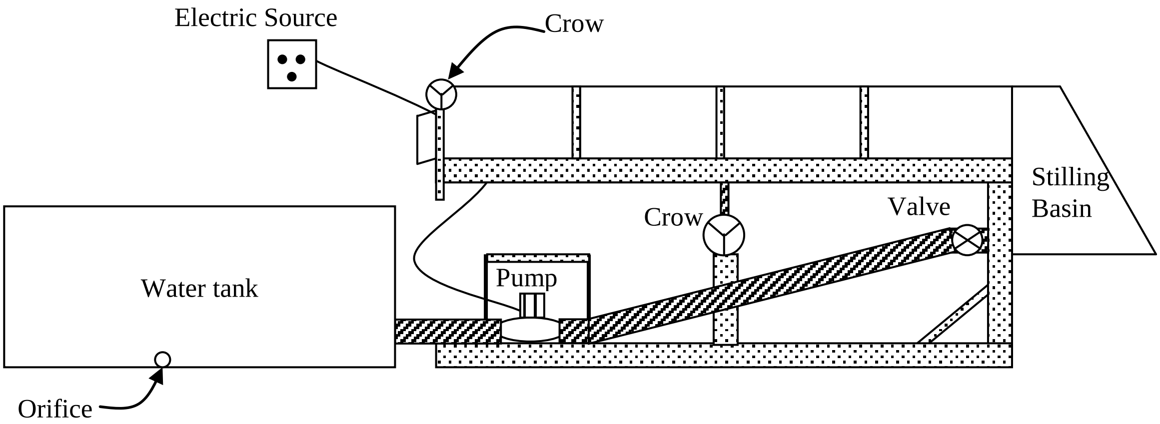

Fig (1): Laboratory channel

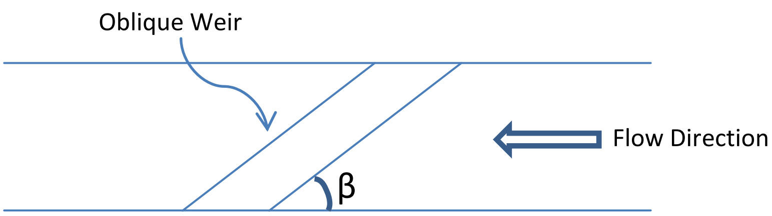

Fig (2): Top View of Oblique Weir and Angle of its Inclination

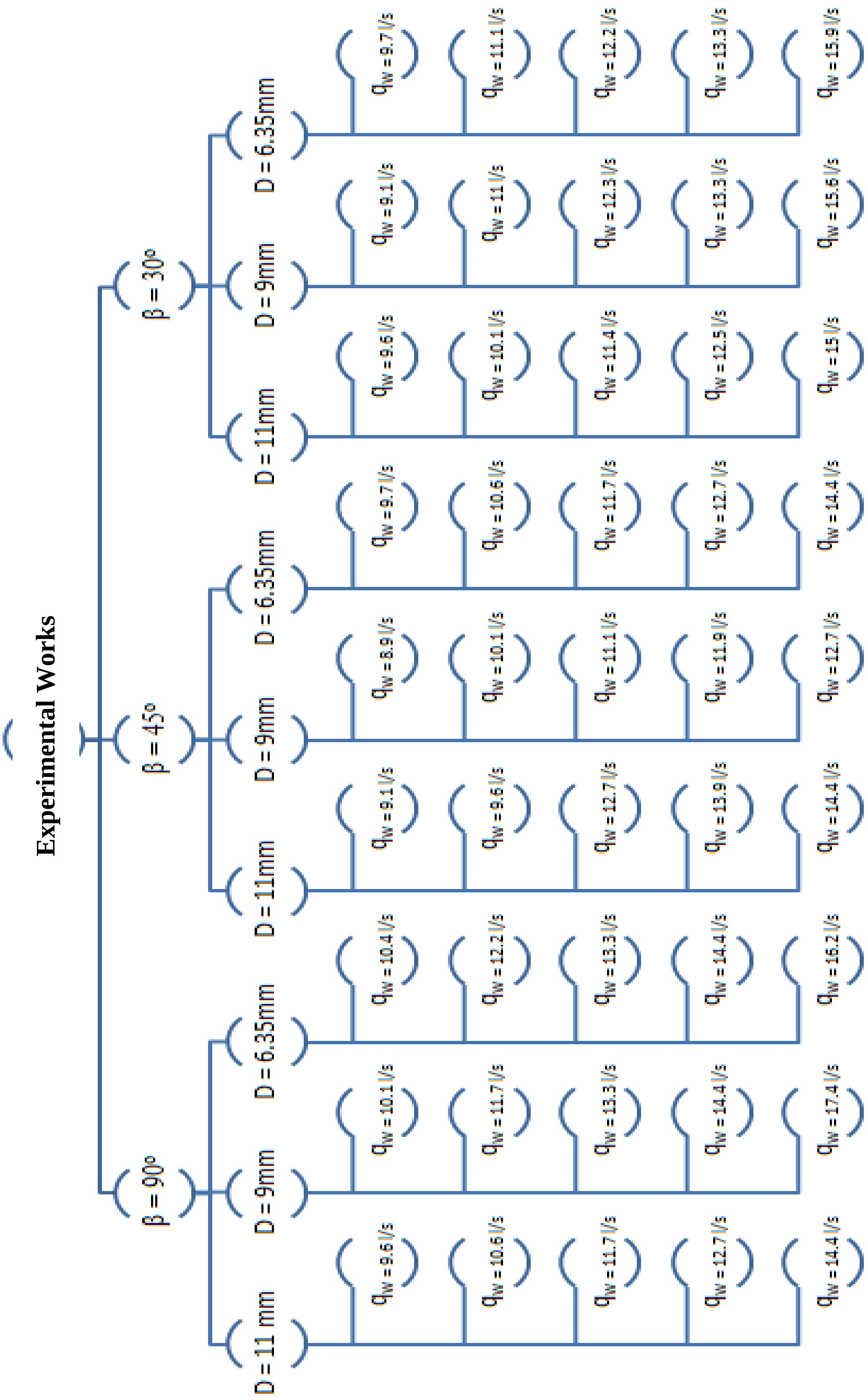

Fig (3): The Experimental Work

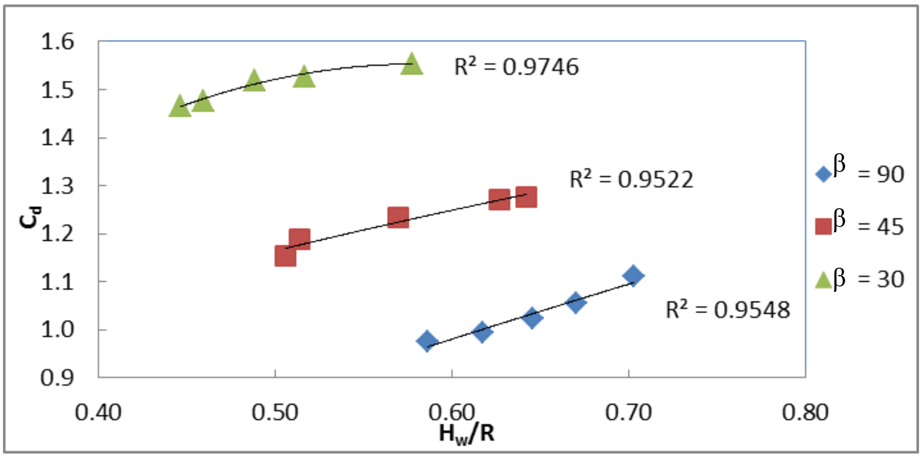

Fig. (4) Relationship between discharge coefficient (C_d) and the dimensionless value (H_w/R) for weir of diameter = 11 cm.

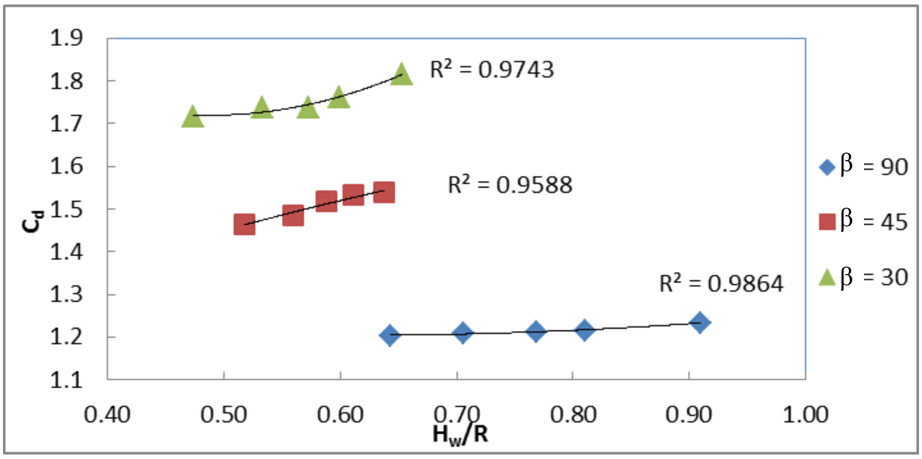

Fig. (5) Relationship between discharge coefficient (C_d) and the dimensionless value (H_w/R) for weir of diameter = 9 cm.

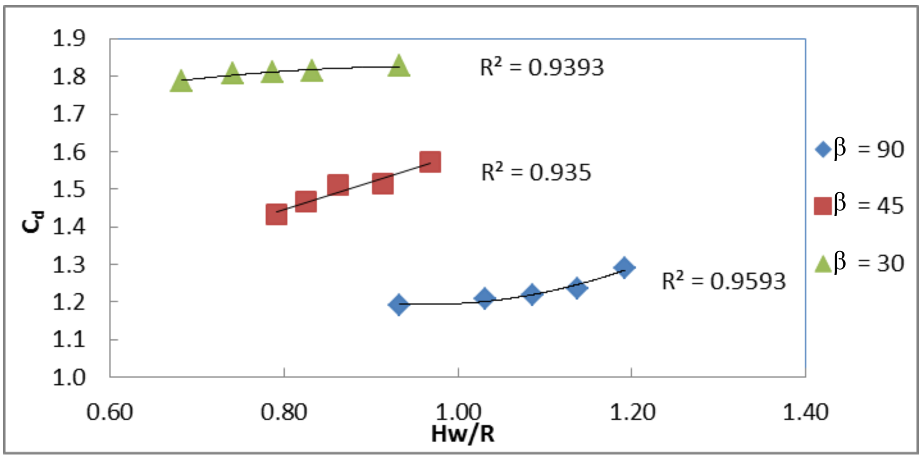

Fig. (6) Relationship between discharge coefficient (C_d) and the dimensionless value (H_w/R) for weir of Diameter = 6.33 cm.

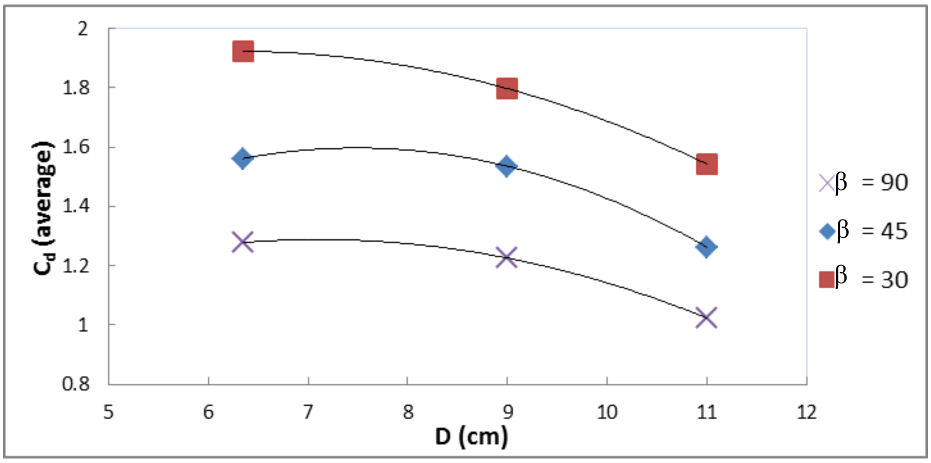

Fig. (7) Relationship between average discharge coefficient (C_d) and the diameter of cylindrical weir (D)

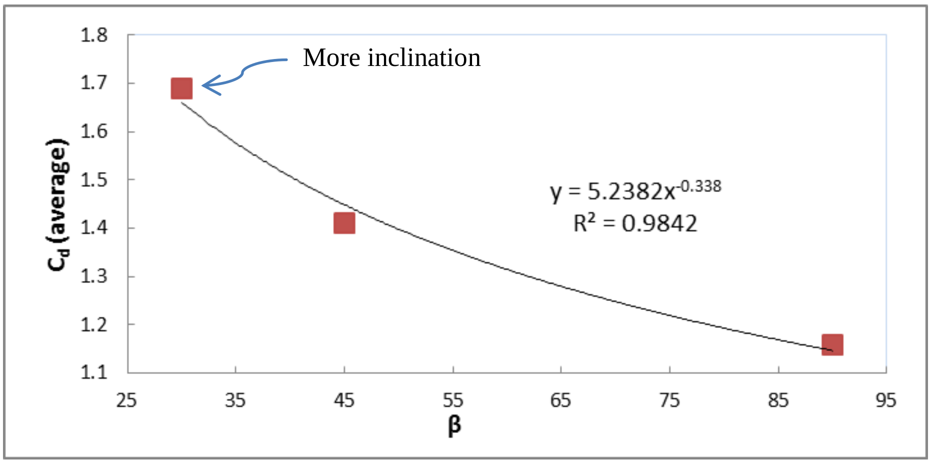

Fig. (8) Relationship between average discharge coefficient (C_d) and the angle of inclination (β) of oblique cylindrical weir.