Journal of Kerbala University , Vol. 11 No.2 Scientific . 2013

Calibrating the Discharge Coefficient of Rectangular with Quarter Circular Edge Crested Weir

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Abstract

This study presents a series of experimental investigations on to calculate discharge coefficient of flow over rectangular weir with quarter circular edge crested extending across the full width of the channel(suppressed) to evaluation the discharge coefficient of the flow. Three weirs were constructed and tested for differentdischarges. They were stable over flow pattern, easy to pass floating debris, has fair coefficient of discharge. Data obtained from laboratory experiments provide information on head - discharge relationship for three models with different height and curvature of weir. Each model has an empirical head – discharge equation.

The predicted values of discharge coefficient for the proposed models were based on measured discharge and the derived discharge equation. Analysis of the results revealed thatdischarge coefficient is proportional withheight and radius of curvatureand with the upstream head above weir crest.

الخلاصة

تهدف الدراسة الحالية إلى إجراء وتحليل سلسلة من التجارب المختبرية لحساب معامل التصريف لسد غاطس مستطيل ذو حافة ربع دائرية موضوع على عرض قناة(غيرمقلص). تم عمل ثلاث نماذج واختبرت بتصاريف مختلفة.تمتاز النماذج بنمط جريان مستقر و بسهولة تصريف المواد العالقة وله معامل تصريف معتدل. اظهرت المعادلات التجريبية التي تم استنتاجها من نتائج التجارب المختبرية عن العلاقة مابين التصريف والشحنة المقاسة لثلاثة نماذج مختلفة. ان قيم معامل التصريف المحسوبة لهذه النماذج معتمدة على قيم التصاريف المقاسة وقيم التصاريف النظرية. تحليل النتائج اظهر ان معامل التصريف يتناسب طرديا مع ارتفاع ونصف قطر التقوس للسد الغاطس وكذلك مع الشحنة مقدم حافة السد الغاطس.

Introduction

Water flowing over weir ischaracterized by a rapidly-varied flow region near the crest. Themost common types of weir crest are the broad-crested weir, the sharp-crested weir and the circular-crested weir. Advantages of the rectangular with quarter circular edge weir shape is the stable overflow pattern compared to sharp-crested weirs, the ease to pass floating debris. The basicdifference between broad crested weir and sharp crested is the curvature of stream lines and larger discharge. The effect of curvature is to produce appreciable acceleration components or centrifugal forces normal to the direction of flow **[1]**. Related applications include three models of polished wood. In the present study, the characteristics of the rectangular with quarter circular edge weir are investigated to determine the relation between the head and rate of discharge.

Previous Researches

Major studies of circular weirs include **[2]**. Theseinvestigations showed that the discharge coefficient Cd was close to and usually larger than unity, and Cdwas primarily a function of the ratio of upstream head to crest radius Hw/R, Cd increasing with increasingvalues of Hw/R, where Hw is the total head above crest and R is the crest curvature radius.**[1]** studied curvilinear flow resulting in diversion of pressure is distribution from hydrostatic as the flow occurs in the vertical plane.**[3]** shown non uniform velocity distribution which has maximum value at the inner surface and lower value at the surface of flow of the circular crested weir. **[4]**, reported the pressure will be less than hydrostatic pressure in convex flow when centrifugal force acting upward against the gravity action.**[5]**conducted some experiments to study the characteristics of the semicircular crested weir. **[6]**reported that the hydraulic characteristics of the circular crested weir depend only on the dimensionless total upstream head H/R and are independent of weir height.**[7]**shown the two dimensional flow patterns over cylindrical weirs can describe by the equation of motion in the s-and n-direction, the rate of departure from hydrostatic pressure distribution is defined by the local centrifugal acceleration (V2/r)figure (1-b). Thus the change of piezometric in n-direction is:

$D\,(\frac{P}{\gamma}+Z)=(-\frac{V^2}{gr})dn$ - (1)

The integration of equation (1) from point (1) to point (2) in the n-direction figure (1-a) yields:

$(\frac{P}{\gamma}+Z)_1 - (\frac{P}{\gamma}+Z)_2 = \frac{1}{g}\int_1^2 \frac{v2}{r}.dn$- - - - - - - - - - - - - - - - (2)

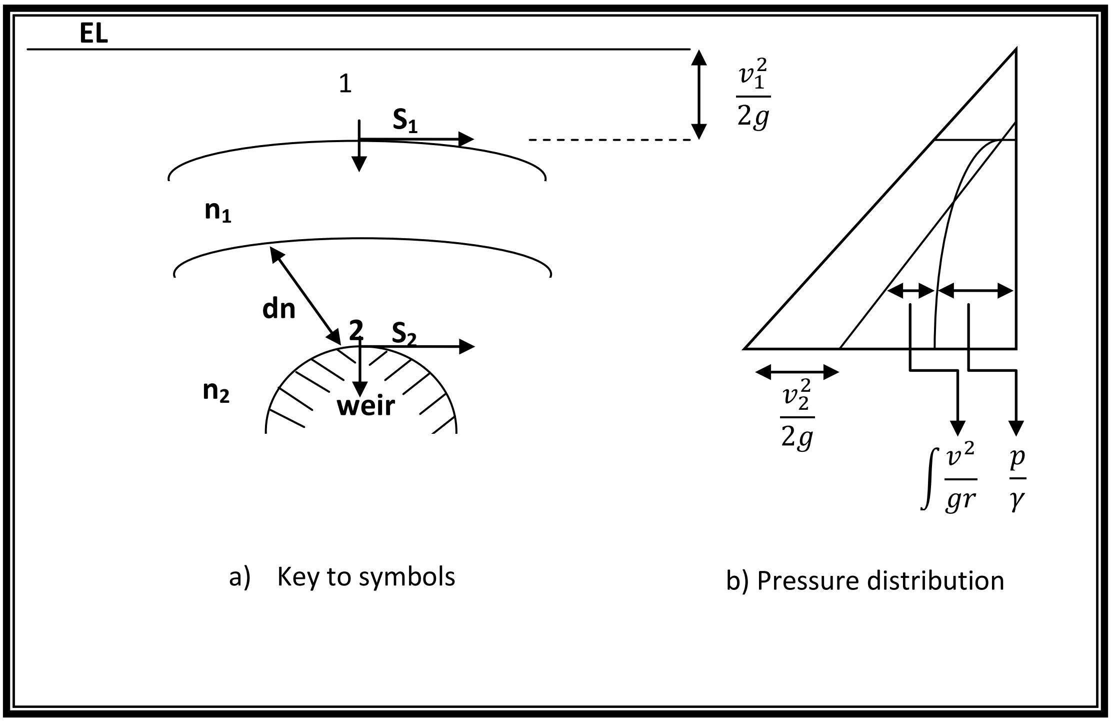
Where:

$(\frac{P}{\gamma}+ Z)$: the piezometric head at point (1) and point(2) respectively.

$\frac{1}{g}\int_1^2 \frac{v2}{r}.dn$: the loss of piezometric head due to curvature of surface line.

A decrease of piezometric head, which is due to centrifugal acceleration, necessarily a corresponding increase of velocity head, thus:

$\frac{V_2^2}{2g}-\frac{V_1^2}{2g} = \frac{1}{g}\int_1^2 \frac{v2}{r}.dn$ - (3)



Figure(1): Convex Flow

Critical depth

In a rectangular horizontal channel with hydrostatic pressure distribution, the flow depth at critical flow condition equals:

$Y_c=(\frac{q^2}{g})^{1/3}$- (4)

Where:

y_c: the critical flow depth at the crest weir, (L).

Critical flow occurs but the pressure distribution is not hydrostatics. The stream line curvature implies that the pressure gradient is less than hydrostatic and velocity distribution is rapidly varied **[8]**. Critical depth and its position on weir are governed mainly by frictional effects and stream line curvature. Therefore, curvilinear flow $(\frac{y_c}{y_1})$ >2/3 while in parallel flow $(\frac{y_c}{y_1})$ =2/3 **[9]**, y_1: the flow of upstream of the weir. For all these reasons, the depth of the rectangular with quarter circular edge weir is expected to differ from equation (4).

Computation of Pressure Distribution

Knowledge of the variation in pressure is particularly important in the design of hydraulic structure, over which and in which flow is a curved nature. The induced pressure forces may cause damage or erosion to the face of the structure. In the vertical plane the effect of streamline curvature is to increase or decrease pressure distribution. Flow over a convex surface the pressure is reducing below hydrostatics**[10]**. The total pressure distribution can be determined analytically by numerical method, experimental data have shown that the average, y_2= 0.61Hw, the corresponding variation of pressure distribution per unit width acting on weir which is equal and opposite direction to force exerted by weir on block of wateris calculated from equation:

$P_w = \frac{\gamma y_1^2}{2} - \frac{\gamma}{2}(0.61Hw)^2$ - (5)

$P_w = \frac{\gamma}{2}(y_1^2 - 0.37Hw^2)$ - (6)

Pw: the pressure per unit width,($FL^{-2}L^{-1}$).

y_1, y_2: are the upstream and downstream weir depths respectively,(L).

Hw: head of water over the weir,(L).

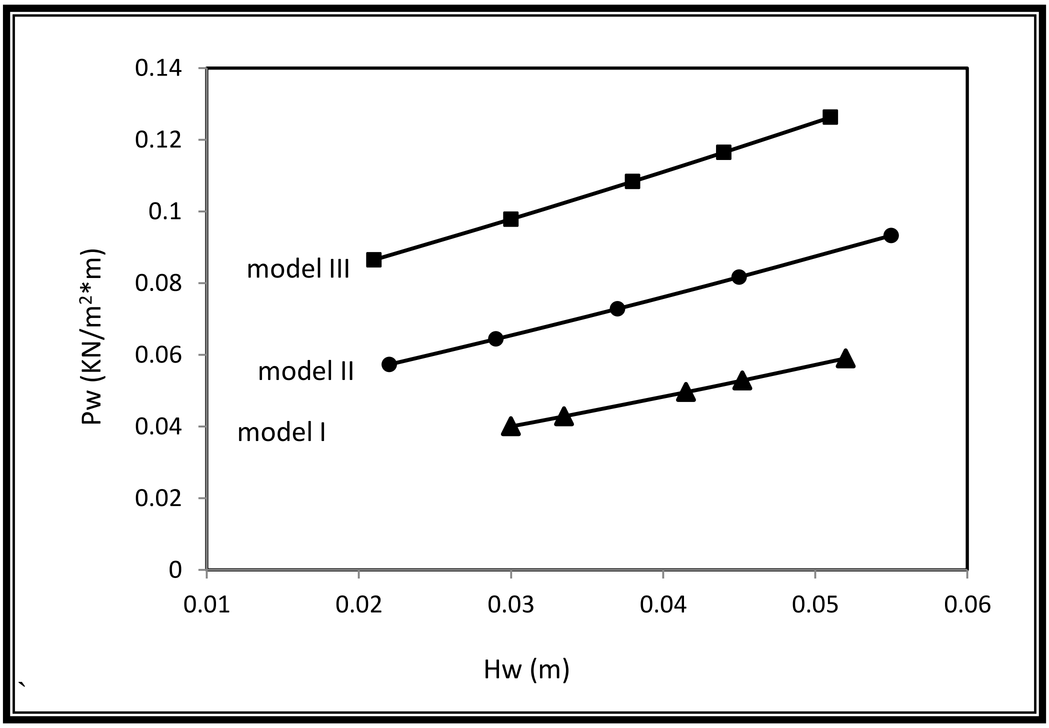


Figure (2): The relationship between (Pw) and (Hw) for three models

Evaluation of Discharge

The discharge per unit width of a broad crested weir across a rectangular channel (q) can be determined by application of the momentum principle. Since it deals only with external forces represented by upstream and downstream hydrostatic and pressure forces which acting on weir surface. The assumptions to be made are the frictional forces(F_f^1).(F_f^2) are negligible, where first symbol is the frictional forces on channel bed and the second is the frictional forces on the weir surface. The longitudinal section of the short length of the horizontal channel shown in the figure (3) in which the flow is impeded by rectangular with quarter circular edge weir located on channel bed.

Let the force exerted by the weir on flow be (Pw) as derived in equation (6). If the momentum equation is applied to the body of water between upstream approach section (1) and downstream section (2) as shown in figure (3), the following equation may be written:

$\frac{q\,\gamma}{g}(\frac{q}{y_2}-\frac{q}{y_1})=\frac{1}{2}\,\gamma\,y_1^2-\frac{1}{2}\,\gamma\,y_2^2-Pw$ - - - - - - - - - (7)

$q_{th}=\left[\frac{g}{\gamma}(\frac{0.61Hw\,y1}{y_1-0.61Hw})*\frac{1}{2}\,\gamma\,y_1^2-0.186\,\gamma\,Hw^2-Pw\right]^{0.5}$ - - - - - - - - - (8)

Where

q_{th}: theoreticaldischarge per unit width($L^3T^{-1}L^{-1}$).

g: gravity acceleration(LT^{-2}).

In practice the observed discharge differs from equation (8) because based on idealized assumption such as: hydrostatic pressure distribution and uniform velocity distribution in reality these effects do occur and must be accounted for by introduction of a discharge coefficient (Cd).

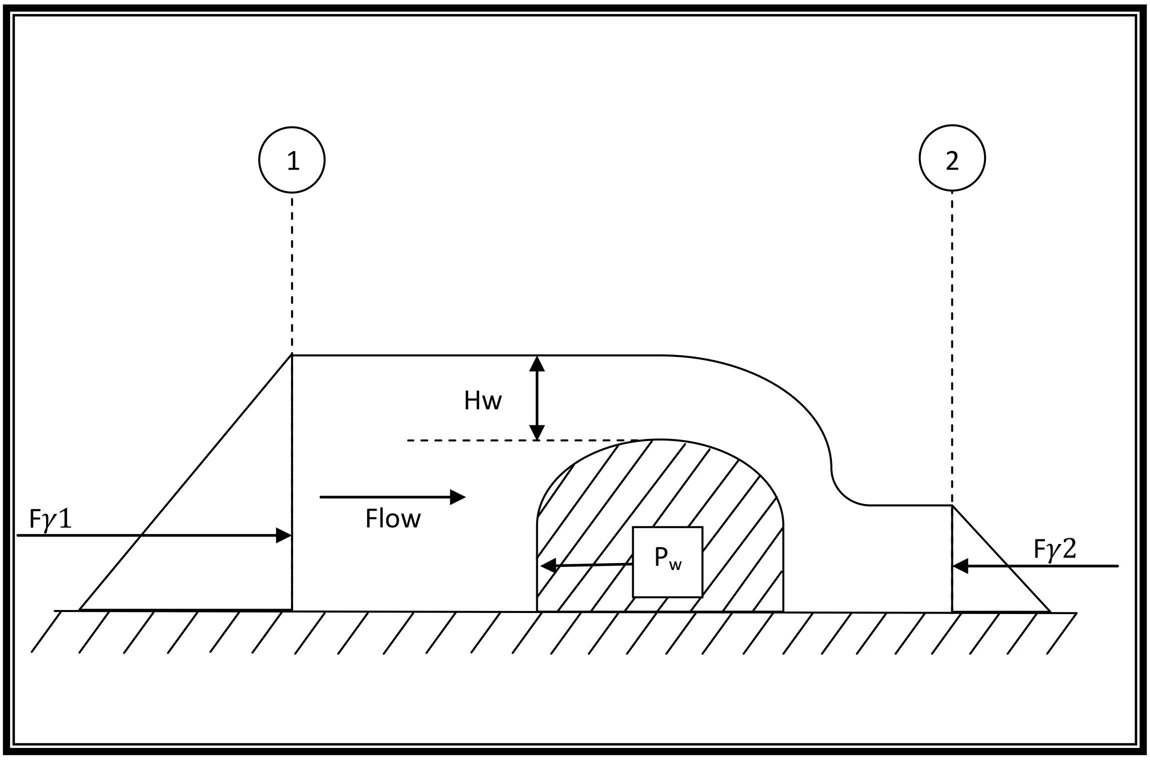


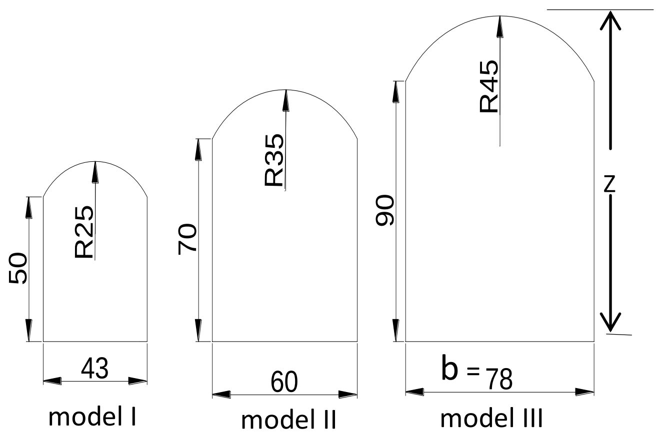
Figure (3): Definition sketch for momentum considerations

Experimental setup and procedure

To determine the discharge coefficient for rectangular weir with quarter circular edge weirthe experiments were conducted in a straight rectangular channel at hydraulic laboratory of University of Babylon, College of engineering, Department of civil engineering of (10) m long (S6-Tilting flume of Slope equal zero) with cross section of (0.3) m width and (0.45) m height. The channel consisted of toughened glass walls and a stainless steel floor figure (4). A point gauge was mounted on brass rails at the top of channel sides.

Figure (4): Flow Patter over the Model (I)

Three weirs model were manufactured from polishedwood and smoothing its surface. The flume is supplied with a constant head tank. The water discharge was measured by a volume-time method, the flow depth had been measured using point gage, and the flow of weir investigated in the laboratory for three models of weir with different high and radius of curvature as shown in figure (5- a, b) which are placed a long (2.5 m)upstream inlet of the tank fixed directly on side walls (suppressed type). The flowregulating value was adjusted to give the maximum possible discharge with the corresponding depth upstream of the weir. The discharge was increase in five steps and series of readings for (q) and (Hw) were taken for each type of weirs.



a- side view for models

b- The Models

Figure(5): Definition sketch for weir

Experimental Results

The variation of (q) with (H) for three models were shown in figures (6),(7) and(8) respectively, with five readings for each models. By plottingq against Hw a straight line relationship obtained its equation of association, ($q=k*H^{m}$) the experimental relation between (q) and (H) are:

$q=17.417*Hw^{2.0395}$ for Model I ------------------ (9)

$q=7.8833*Hw^{2.0579}$for Model II ----------------- (10)

$q=0.2201*Hw^{0.7028}$for Model III ----------------- (11)

Experimental data shows that the practical range of the coefficient (k,m) are varied as shown in table (1).

Table(1): Values of Coefficients for models

Type of Model	k	m	R^2
Model I	17.417	2.0395	0.9985
Model I I	7.8833	2.0579	0.9976
Model I II	0.2201	0.7028	0.9982

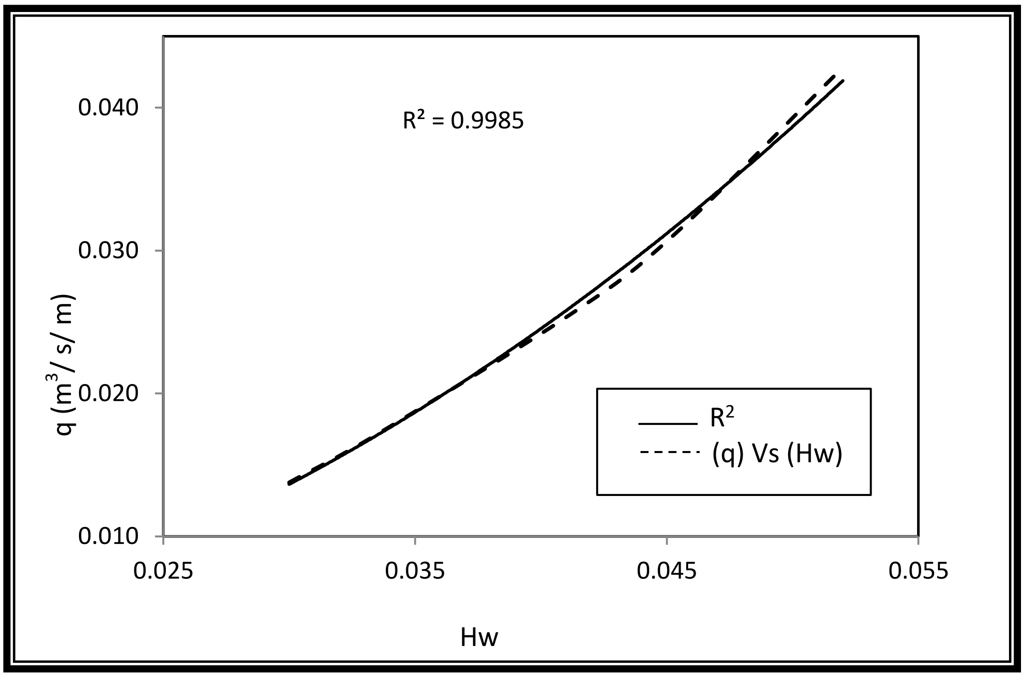


Figure (6): The relationship between (q)with (Hw) for model I

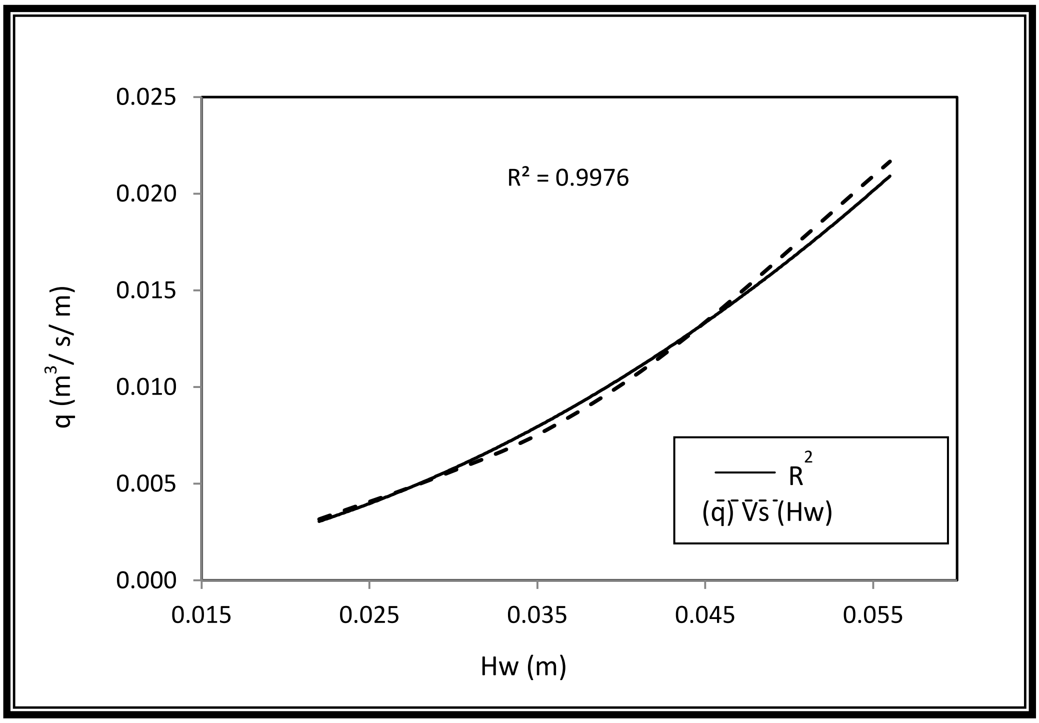


Figure (7): The relationship between (q) with (Hw) for model II

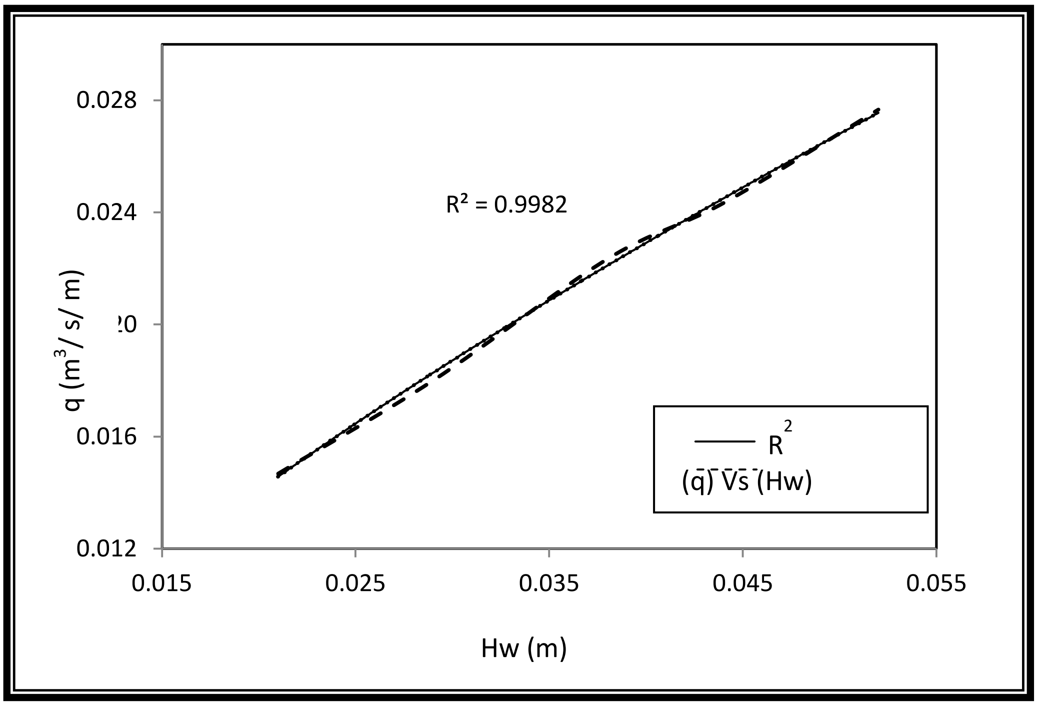
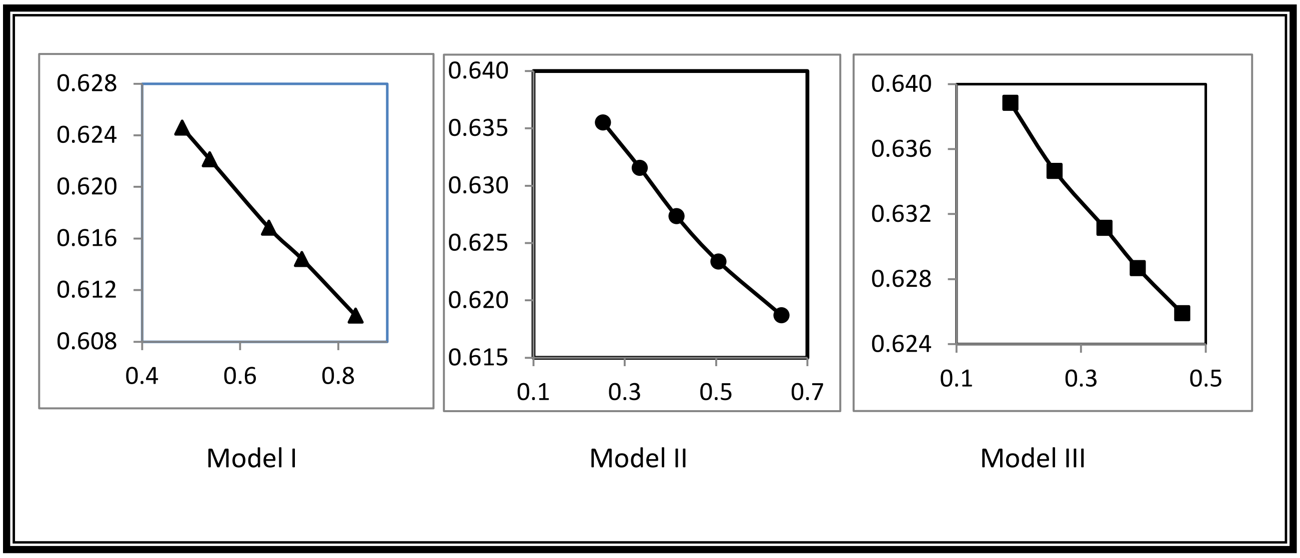


Figure (8): The relationship between (q) with (Hw) for model III

Discharge coefficient

The discharge coefficient data are plotted as function of ratio (Hw/Z). The graphical representation show that the discharge coefficient is proportional to the ratio of (Hw/Z) as illustrated in fig (9). It appears that if curvature very big the stream lines are straight but if they are curved there is a significant flow velocity result is decreasing of discharge coefficient.



Figure(9): The relationship between (Cd)with (Hw/Z)

Also the effect of height and curvaturewere investigated through series of experiments. The average of discharge coefficient(Cd (average)) for each model are plotted versus height (Z) of weir as shown in figure (10) which reveal that the discharge coefficient increased when the height and the curvature of weir increased.

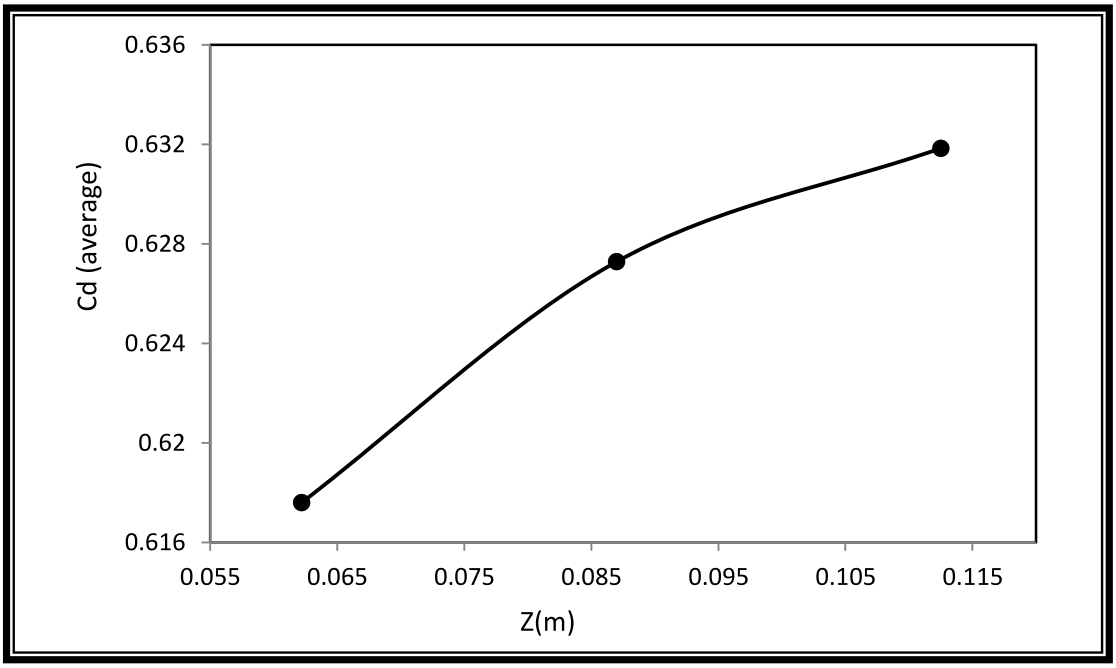


Figure (10): The relationship between (Cd)averages with (Z)

Simulation of flow

During the simulation of flow for rectangular weir, the discharge (q) was found to be effected by a number of variables. A general non-dimensional equation for the discharge through a weir can be written as:

$$\mathbf{q = f\left(\frac{Hw}{Z}, \frac{Hw}{b}, C_d\right)} \text{------------------} \quad (12)$$

A multiple nonlinear regression analysis has been used to predict the valuesof (q) to both hydraulic and geometrical parameters. The following equation fit the data with excellent value of coefficient of multiple determinations (R^2) and the value of standard error of estimate (SEE):

$$q = a*\frac{Hw}{Z} + b*\frac{Hw}{b} + c*C_d + d \quad \text{-------------------} \quad (13)$$

Where:

a,b,c,d: coefficients, in this work, (**Data-Fit** Version9.0 software) was use to estimate the respective values.

Table (2) shows the values of (a,b,c,d) for the weir with their respective value of (R^2) and (SEE). Figure (11) shows the relationships between (q) measured and (q) predicted by eq. (13)**.**

Table (2):Values of coefficients for predicted (q)

Type of model	a	b	c	d	R2	SEE
Model I	-2.56231	0.22297	0.41095	-0.14764	0.9999	1.0345 E-04
Model I I	-65.19202	-24.84845	13.067366	9.210289	0.9994	3.2833 E-04
Model I II	1.33893	0.47723	-0.11753	-0.30421	0.9999	8.9987 E-05

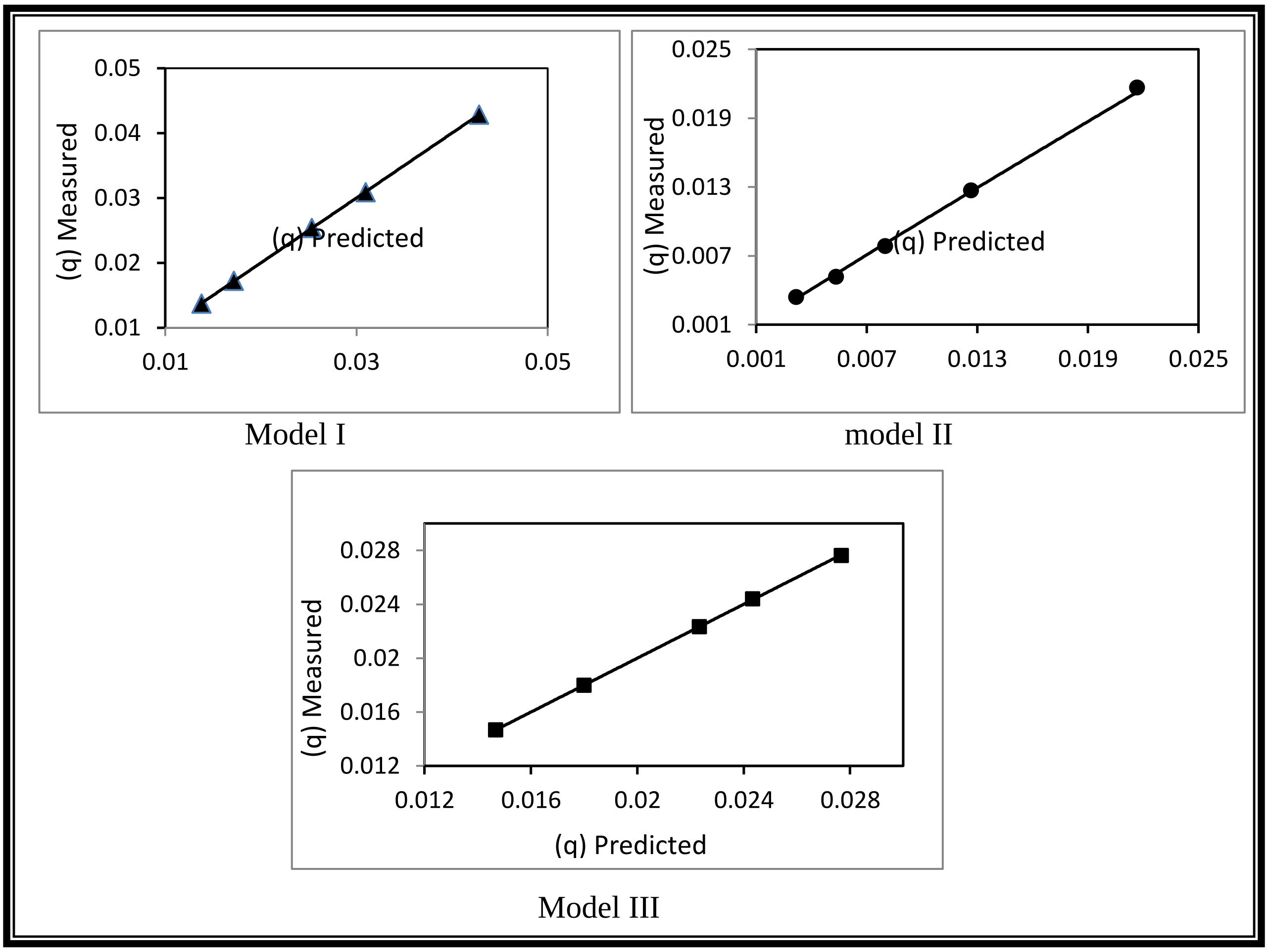


Figure (11): The relationship between (q) measured and (q) predicted

Discussion

A-Pressure distribution

The existence of centrifugal forces in the upstream and downstream cross section is bounding the considered zone of acceleration causing increasing in pressure and discharge coefficient.

B-Weir Coefficient

In the head –discharge equation of each type of models, there is a weir coefficient which represents the combination of the approach velocity head at measuring station. Thus the influences of all values are included in weir coefficients (K) and(m). The practical ranges of the coefficients (K) and(m) are shown in table (1).

C-Discharge Coefficient

The variation of discharge coefficient (Cd) with respect to head normalized to height and radius of curvature (Hw/Z) show that the discharge coefficient is greatly affected by the upstream head over the crest (Hw) and the discharge coefficient values decreasing with increasing values of (Hw) over range of the calibration note that the flow over weir was independent of downstream water level and all results shown in figure (9).

Conclusion

The main objective of this study is to estimate the discharge coefficient forrectangular weir**.** The experimental results and theoretical discharge equation show that the discharge coefficients decrease with us the head upstream the weir crest increased, the height and degree of curvature of over flowing has a significant influence on (Cd) and discharge coefficients increase if the streamlines curvature increases. Thus the discharge coefficient is depending on shape and type of the measuring structure.

From practical experiments there are three different value of (k)and (m) these values are depend on the shape of approaching channel section and the power of the head above the crest level. Each of the empirical stage – discharge equations (9,10,11) of this type have been derived for that structure only.

The pressure distribution varies along the weir surface and the experimental results show the pressure increasing when the head upstream increasing.

A multiple nonlinear regression model was predicted from the measured hydraulic and geometric parameter with excellent values of coefficient of multiple determinations (R^2) and the value of standard error of estimate (SEE).

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