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NUMERICAL SIMULATION AND EXPERIMENTAL STUDY OF HYDRAULIC PERFORMANCE OF CIRCULAR CRESTED NORMAL WEIRS

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ABSTRACT

Weirs are simple control structures usually built across channels for water storage and measurement of flow rates. The main target of the present study is to numerically simulate and experimentally study the hydraulic performance of circular crested normal weirs. For numerical simulation, the commercial package ANSYS CFX is utilized adopting tetrahedrons mesh with a maximum total number of 1932301 elements, while, for the experimental study nine physical models are manufactured and tested having different crest diameters and various weir heights. Numerical simulation results demonstrated that the ANSYS CFX software is highly capable for simulating circular crested normal weirs showing quite good agreements in water surface profiles and 4.3% mean percentage error in upstream head above crest, while, the software showed 6.8% mean percentage error in estimating discharge coefficient. A simple empirical expression is obtained for the estimation of coefficient of discharge in terms of ratio of upstream head to weir height and the ratio of upstream head to crest diameter with a coefficient of correlation = 0.88. The flow rate magnification is found increasing with the increase of upstream relative head and the best performance of the weir is found when the ratio of crest diameter to weir height = 0.33 at which the highest increase in flow rate is observed ranging between 25.41% and 32.14% compared with sharp crested weirs having the same height and the same length of crest.

KEYWORDS: Numerical simulation; Normal weirs; Circular crests; Hydraulic performance; Discharge magnification.

1. INTRODUCTION

Due the rapid growth of the world population, construction of storage water structures (for example dams and weirs) with cheap materials in order to make large quantities of water available is hydrodynamic and economic important problem facing hydraulic engineers. This problem needs intensive experience and work from water engineers to design and construct various hydraulic structures with low cost (Noori, 1985). Sharp crested rectangular normal weirs are the simplest hydraulic structures built across streams or channels in order to raise the upstream water levels for storage purposes and at the same time to pass water over them for flow rate measurements. It is also necessary to provide more flood storage as well as to pass maximum flood safely via the large capacity of the weir to overpass flow rates (Aaref, 2016 and Noori and Aaref, 2017). In case the weir cannot adequately pass the flooded flow rate, it is so important to enhance the discharge capacity of the weir otherwise in case of limited width normal weirs cause the increase of afflux submerging the country sides and costly people's properties (Noori, 1985 and Noori and Aaref, 2017). Many investigators have studied different parameters impacting the coefficient of flow rate of sharp crested normal weirs (Rehbock, 1929, Rouse, 1936, Kindsvater and Carter, 1957) concluding that the most effective parameter is the head above crest to crest height ratio. The impact of crest width on the discharge equation is considered as an important parameter especially in case of small values of head above crest to width of crest ratio (Johnson, 2000). Efficiency

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and behavior of the weir can be enhanced and improved by increasing the flow rate coefficient of the weir featured with stable surface profiles of overpassing flow rates (Chilmeran, 1996, Noori and Chilmeran, 2005, Bachaya et al., 2019). Chanson and Montes (1998) conducted an important laboratory investigation on the characteristics of flow passing over cylindrical weirs for wide ranges of cylinder radius, upstream flow conditions and upstream hydraulic jumps concluding that the cylinder size has no impact on the coefficient of flow rate. The earliest experimental studies on rounding the crest of the weir in order to increase the efficiency and performance of weirs were those due to Chilmeran (1996) and Noori and Chilmeran (2005) through experimenting semicircular crested normal and oblique weirs and presenting a direct expression for the prediction of flow rate coefficient as a function of relative upstream water head above crest, ratio of crest radius to weir height and oblique angle of the weir with side wall. Tullis et al. (1995) improved the efficiency of weirs having trapezoidal plan form shape by giving quarter round shape to the crest. Half and quarter rounded crests are tested in trapezoidal plan form labyrinth weirs by Crookston and Tullis (2011) concluding that weirs of half round shape of crest have higher efficiency and best performance. Quarter round crest shapes are used for labyrinth weirs by Lux and Hinchliff (1985) trying to increase the efficiency of labyrinth weirs. Tingey (2011) tested different oblique weirs having half round and quarter round crest shapes showing that weirs of half round crests offer higher flow rate efficiency and better behavior.

An intensive study has been presented by Noori and Aaref (2017) to enhance the capacity and behavior of weirs of triangular plan form shapes via circulating the crests depicting that the coefficient of flow rate falls with the rise of upstream water head to crest height ratio and small diameters of crest give higher flow rate efficiency and best behavior. The best performing ratio of crest diameter to weir height is suggested as 0.17. A recent laboratory investigation on the hydraulic behavior of oblique weirs having circular crests has been conducted by Noori (2020) in which twenty-four weir models have been tested for various values of crest diameter and weir height concluding that circulating the crest improves the flow rate efficiency and the behavior of the weir and the best performance is found when having the ratio of crest diameter to weir height equals to 0.2. The discharge intensity was increased by 147% to 175% compared to sharp crested normal weirs.

In this investigation, a trial has been made to enhance the efficiency and performance of normal weirs through circulating the crests and to numerically simulate the free flow overpassing normal weirs having circular crests. The experimental part of this study included the construction and testing of nine physical weir models having various weir heights and different diameters of crest. Moreover, the present investigation aims to examine the water surface profiles overtopping these types of weirs and to present an expression for the prediction of flow rate coefficient in order to be invested in the design of normal weirs having circular crests.

2. EXPERIMENTAL WORK

The experimental work of the present investigation was conducted at the Fluid Mechanics Laboratory of Engineering College of Duhok University. The tests are carried out in a five-meter length tilting flume having 0.3 m x 0.45 m cross section. A centrifugal pump was used for circulating water having a maximum capacity of flow rate of 0.040 m^3/s. For the experimental part of the present study, nine weir models are constructed from PVC pipes and Perspex sheets. Based on the diameter size of the crest, the models are classified into three groups. In the three weir models of group one, the crest diameter is kept constant (D = 50 mm), but the height of the model is varied three times as (P = 150, 200 and 250 mm). For the other groups, the crest diameter is changed as (D = 75 and 110 mm) also the height of the model is varied three times similar to group one. Table 1 shows full details of the laboratory work program. For the whole testing work, the laboratory flume is set horizontal and every model is set perpendicular to flume sides and fixed at 2 m upstream the flume outlet and within a clear glass panel to clearly monitor the water flow overtopping the weir crest. Seven variable flow rates are allowed to overpass each weir model starting with a low value of flow rate. The flow rates are recorded via a calibrated flow meter having the accuracy up to 0.01 l/s. Surface profile measurements are recorded for each run by taking water depth measurements for small intervals along the center line of the flume by a movable pointer gauge elevated on a pair of brass rails on the flume sides. The pointer gauge was capable of reading depths to an accuracy of 0.1 mm. Sixty-three experiments are carried out during the testing work as in Table 1. The ranges of water depth above crest (h) and ranges of flow rate (Q_{nc}) are also presented in Table 1.

Table 1. Details of models and ranges of both head above crest and overpassing flow rates

	Model	Diameter Crest D (mm)	Model height P (mm)	Range of h (mm)	Range of Q_{nc} (l/s)	No. of runs
1	1	50	150	32.1 – 95.1	3.95 – 22.30	1 – 7
	2	50	200	30.9 – 90.9	3.46 – 19.02	8 – 14
	3	50	250	30.5 – 90.5	3.17 – 17.90	15 – 21
2	4	75	150	32.9 – 94.1	3.90 – 20.79	22 – 28
	5	75	200	30.9 – 92.9	3.38 – 19.15	29 – 35
	6	75	250	31.2 – 92.5	3.25 – 17.89	36 – 42
3	7	110	150	33.2 – 91.2	3.87 – 19.48	43 – 49
	8	110	200	31.5 – 90.0	3.37 – 17.95	50 – 56
	9	110	250	31.5 – 90.0	3.25 – 17.09	57 – 63

3. THEORETICAL CONSIDERATIONS

3.1 Dimensional Analysis

The performance of free flow overpassing circular normal weirs with circular crests is considered to be affected by the flow properties and the geometry of the weir including the following variables: flow rate overtopping the weir (Q_{nc}) [L^3T^{-1}], upstream mean velocity of the channel (V) [LT^{-1}], upstream head above crest (h) [L], height of the weir (P) [L], diameter of the crest (D) [L], gravity acceleration (g) [LT^{-2}], water mass density (ρ) [ML^{-3}] and water dynamic viscosity (μ) [$ML^{-1}T^{-1}$]. A general function of the forgoing variables can be expressed as:

$$\emptyset_1(Q_{nc}, V, h, P, D, g, \rho, \mu) = 0 \qquad (1)$$

Applying dimensional analysis (Pi-theorem) to Eq. (1) with certain manipulations yields the following expression:

$$C_{dc} = \frac{Q_{nc}}{\frac{2}{3}\sqrt{2g}\,B\,h^{1.5}} = \emptyset_2\left(\frac{h}{P}, \frac{h}{D}, R_e\right) \qquad (2)$$

where, C_{dc} = coefficient of discharge of circular crested weir, B = channel width (crest length) and R_e = Reynolds number in the upstream channel. Because the range of Reynolds numbers in the upstream channel were turbulent and between 3720 and 28220, the viscous forces are weak compared to inertial forces, thus, R_e may be ignored (Chow, 1959). Hence, Eq. (2) may reduce to the following form:

$$C_{dc} = \frac{Q_{nc}}{\frac{2}{3}\sqrt{2g}\,B\,h^{1.5}} = \emptyset_3\left(\frac{h}{P}, \frac{h}{D}\right) \qquad (3)$$

Eq. (3) demonstrates that the coefficient of flow rate for normal weirs of circular crests is a function of the ratios of water head over crest to height of weir and water head over crest to the diameter of crest. A definition sketch is shown in Figure 1.

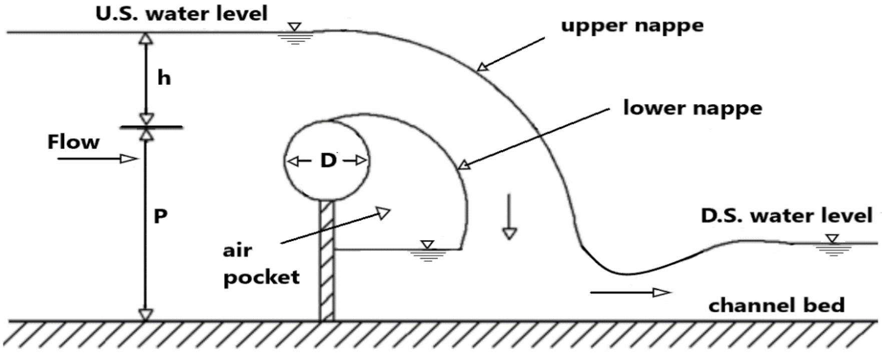

Fig. (1): Definition sketch

3.2 Governing Equations for Numerical Solution

In general, most of the computational fluid dynamic codes (CFD) used the Reynolds Averaged Navier-Stokes (RANS) for turbulent flow modeling. The numerical model is mainly dependent on the technique of discretization of finite volume method which satisfies the mass and momentum conservation equations for three dimensional, turbulent and incompressible fluids (ANSYS-CFX-help).

The mass and momentum conservation equations for incompressible flow may be shown in tensor form as:

Mass conservation equation:

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i}(\rho U_i) = 0 \qquad (4)$$

Momentum conservation equation:

$$\frac{\partial(\rho U_i)}{\partial t} + \frac{\partial}{\partial x_j}(\rho U_i U_j) = -\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right)\right] + \frac{\partial}{\partial x_j}\left(-\rho\overline{\acute{u}_i \acute{u}_j}\right) \qquad (5)$$

where,

ρ = density of water, t = time, x = coordinate axis, U_i = mean velocity component, P = mean pressure, μ = dynamic viscosity of water and $\acute{u}_i$ = fluctuating part of velocity.

The term $\left(\frac{-\,\partial(\rho\overline{\acute{u}_i \acute{u}_j})}{\partial x_j}\right)$ of Eq. (5) is referred to as the Reynolds stresses term, through which turbulence is modeled and the RANS system to be closed.

For modeling the profile of the free surface, volume of fluid (VOF) method is used as a model of multiphase. In case of flow with a free surface, every cell has a part of water if it is totally filled by water α_w =1 but if it is totally filled with air α_w = 0. While, others are partially filled by water when the volume fractions is ranging between 0 and 1 (Nikseresht et al., 2009).The following equation is utilized to define the percent of fluid in volumes:

$$\frac{\partial \alpha_w}{\partial t} + u_i \frac{\partial \alpha_w}{\partial x_i} = 0 \qquad (6)$$

where,

α_w = fraction of water volume, t = time, and u_i = x_i - direction velocity.

Fractions of air phase volume may be found by the expression:

$$\alpha_a = 1 - \alpha_w \qquad (7)$$

In the present study, the steady state, incompressible fluid and RNG $k-\varepsilon$ model of turbulence is used to simulate overpassing flow over circular crested weir. This model has been used to renormalize the equations of Navier Stokes for considering the impacts of the small turbulence motions and separated flows. In addition, to increase the accuracy of multiphase simulation an advection scheme of high resolution is utilized for mass and momentum and the first order scheme is used for dissipation rate and turbulence kinetic energy.

3.3 Simulation of Numerical Model

3.3.1 Geometry of model and mesh generation

ANSYS Design Modeler is used to generate the geometries of the flow region. The fluid domain is consisted as a 3D-rectangular open channel of 5 m length, 0.45 m height and 0.3 m width and the model is located inside the fluid domain for which the model's bottom right corner of is located at the origin point of the coordinate system as shown in Figure 2.

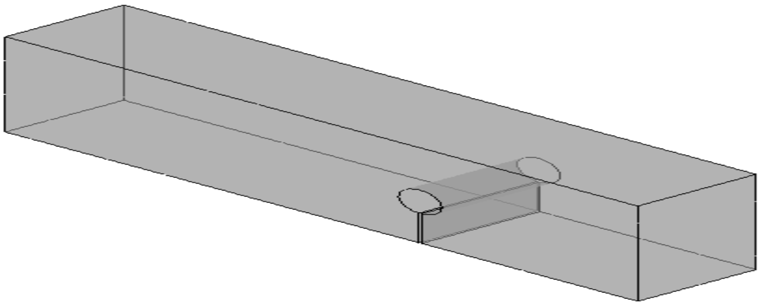

Fig. (2): Geometry of the model

For circular crested normal weir, the tetrahedrons mesh type is used. The maximum total number of elements used for this study was (482238), see Figure 3. Adaption of mesh is applied, in which the mesh is automatically refined during the simulation process (ANSYS-CFX-help). The maximum number of mesh elements after generating mesh adaption was (1932301) for circular crested weirs, see Figure 4.

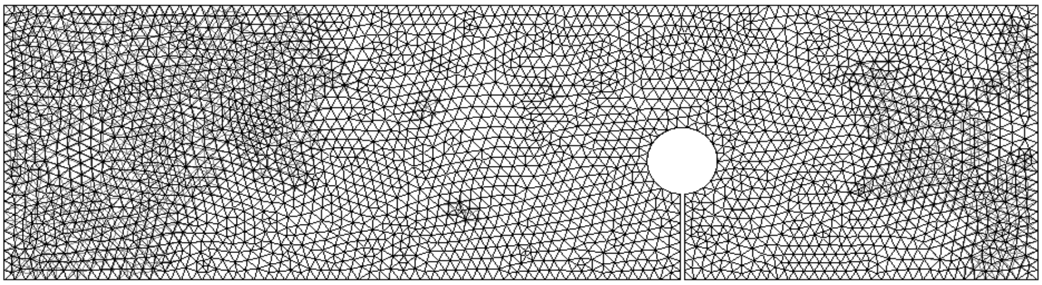

Fig. (3): Typical view of mesh for circular crested weir

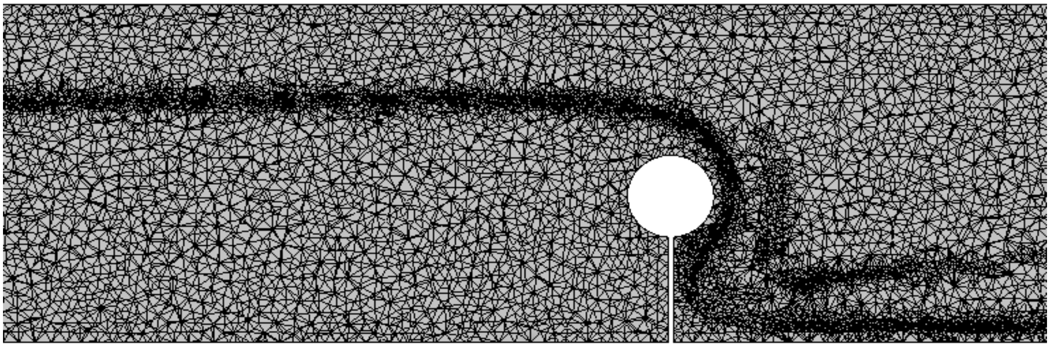

Fig. (4): Mesh adaption (finer mesh at water surface) for circular crested weir

3.3.2 Simulating boundary conditions

In ANSYS CFX code, several types of boundary conditions are available to model inlets, outlets, free surface and walls. To simulate flow rates overpassing circular crested weir of the present investigation, flow rate boundary conditions are applied at the inlet section of the channel and the pressure at the outlet. The other three domain surfaces (front, back and bottom) are described as smooth solid walls of non-slip boundary condition. For the purpose of presence of free surface, the opening boundary type with entrainment and zero relative pressure was defined at top surface.

4. RESULTS AND DISCUSSION

4.1 Flow Surface Profiles

The numerical simulation results for water surface profiles above crest are compared with those obtained experimentally showing quite good agreements. A sample of comparison is shown in Figure 5 for flow runs overpassing a weir of height of 150 mm and diameter of crest of 50 mm for a range of overtopping flow rates between 3.95 and 22.3 l/s and the corresponding heads over crest (h) between 32.1 and 95.1 mm, respectively for model number one, see Table 1. The dimensionless water surface profiles predicted from the numerical solution along the center line of the flume for all experiments on the first weir are plotted in Figure 6 (Y/h versus X/h), where, Y is the depth of water measured over model crest at upstream horizontal distance away from the model crest center (X).

The main advantage of measuring surface profile of flow is that to locate the nearest region of uniform flow at which the water depth above crest remains constant in order to place a pointer gauge at this location for the measurement of upstream head above crest (h) which is the main variable in calculating the flow rate overpassing the crest. The maximum X-distances recorded experimentally for the water head to become horizontal are ranging between X = 3.1 h and X = 4.6 h for all circular crested weirs of different heights and various crest diameters. While, the maximum X-distances predicted by the numerical simulations of the models are ranging between X = 3.73 h and X = 5.65 h for all models.

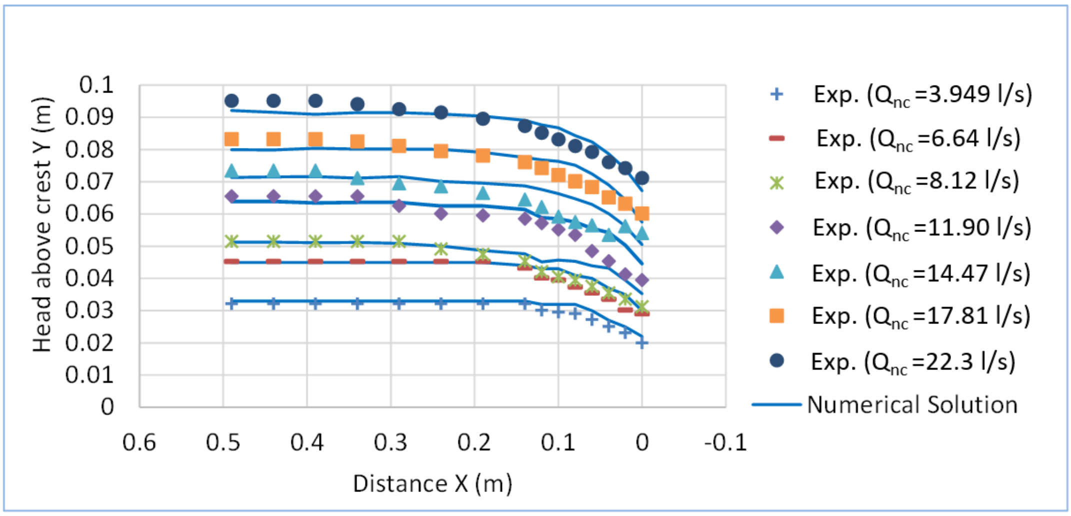

Fig. (5): Comparison of water surface profiles between numerically predicted results and experimentally measured ones (Model No. 1, D = 50 mm and P = 150 mm)

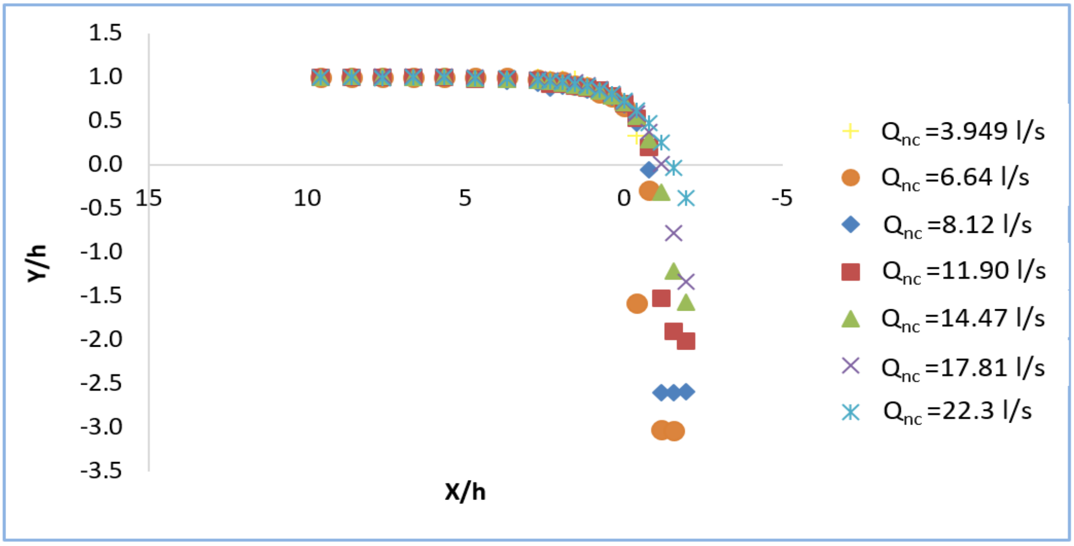

Fig. (6): Y/h versus X/h along flume center line for model No. 1 (D = 50 mm and P = 150 mm) predicted from the numerical solution

4.2 Relationships Between Flow Rate and Water Head Above Crest

It is important to plot the relationships between the flow rate overtopping the circular crested weir models (Q_{nc}) with the head above crest (h) experimentally and then comparing them with the numerically predicted ones in order to verify the numerically predicted ones. The relationships of (Q_{nc}) with (h) are investigated for various heights and different crest diameters of the weir models. The relationships between (Q_{nc}) and (h) while keeping the crest diameter constant (D) = 50 mm for various heights of model (P) = 150, 200 and 250 mm are illustrated in Figure 7 showing that the flow rate rises with the rise of water head over model crest and small height weir model (P = 150 mm) allows higher flow rates compared with those of higher heights. Similar relationships are plotted for weir models of larger diameters of crest (D = 75 and 110 mm) in Figures. 8 and 9 showing similar patterns of curves and also demonstrating that weirs of smaller heights overpass higher flow rates. The numerically predicted relationships between (Q_{nc}) and (h) are compared with the experimental obtained results in Figures 7, 8 and 9 showing good agreements. This demonstrates that the numerical simulation program is highly capable to simulate the relationships between of flow rate and upstream water head above model crest for normal weirs having circular crests.

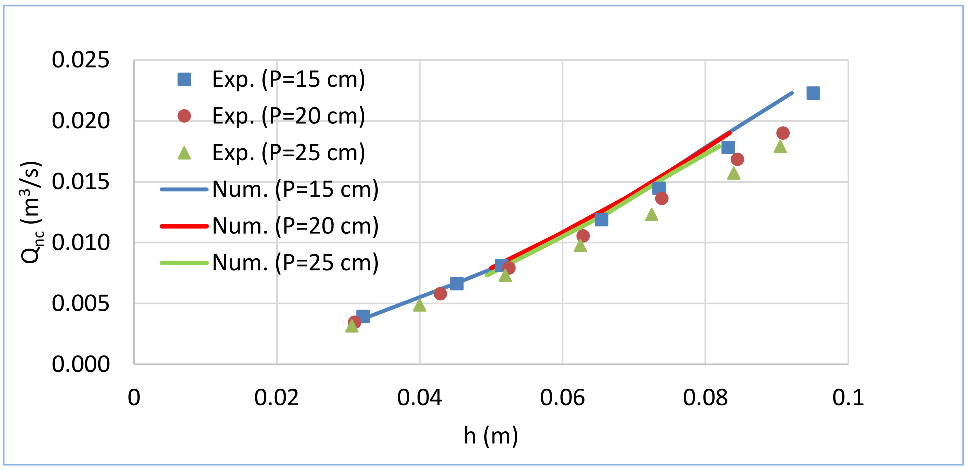

Fig. (7): Relation between (Q_{nc}) and (h) for D = 50 mm and various model heights

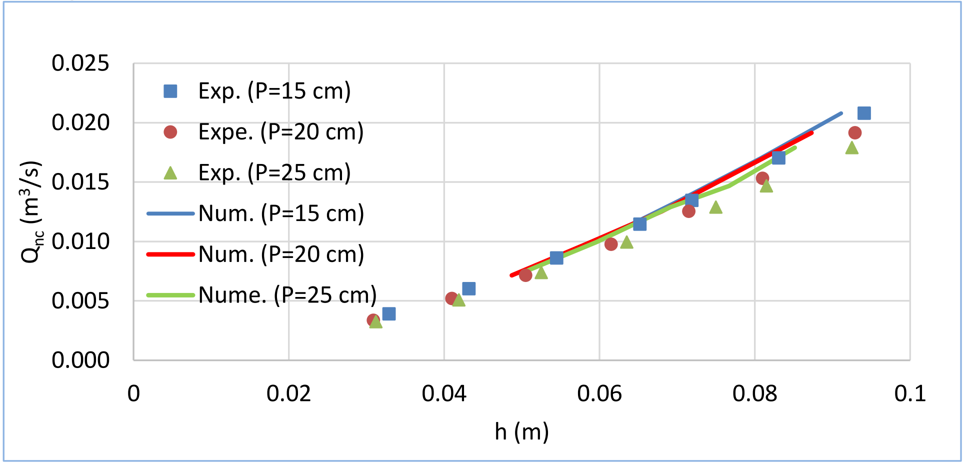

Fig. (8): Relation between (Q_{nc}) and (h) for D = 75 mm and various heights

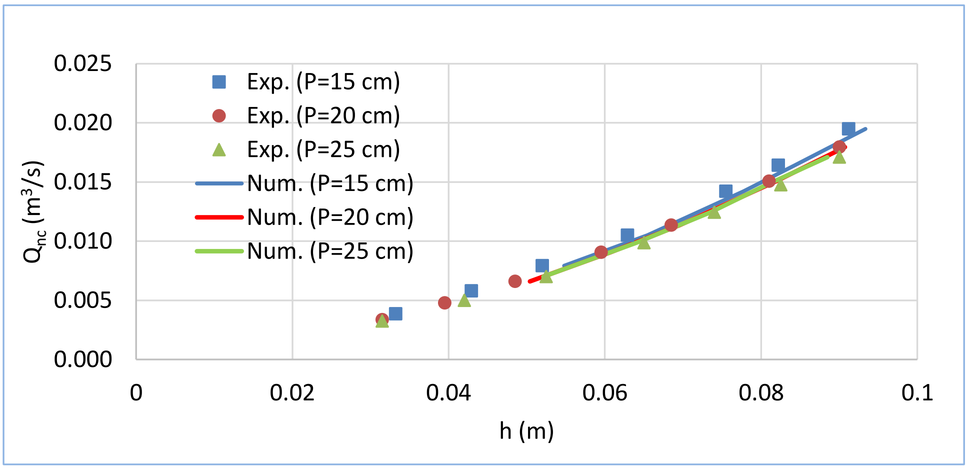

Fig. (9): Relation between (Q_{nc}) and (h) for D = 110 mm and various mode heights

4.3 Coefficient of Flow Rate

As shown in Eq. (3) the coefficient of flow rate (C_{dc}) is dependent on both relative upstream water heads above crest (h/P) and (h/D). The variations of (C_{dc}) with (h/P) for constant value of diameter of crest (D = 50 mm) and the three different heights of weir model (P = 150, 200 and 250 mm) are plotted in Figure 10. Curves for variations of (C_{dc}) with (h/P) for constant diameters of crest (D = 75 and 110 mm) and different heights of weir model are illustrated in Figures 11 and 12. One can clearly realize from Figures 10,11and 12 that the coefficient of flow rate (C_{dc}) values rise with the rise of (h/P) values if the crest diameter is kept constant and models of smaller heights give higher values of (C_{dc}). Noori and Aaref (2017) and Aaref (2016) in their study of circular crested triangular planform weirs and Noori (2020) in his study of performance of circular crested oblique weirs achieved a similar outcome conclusion. It is quite important to study the impact of crest diameter (D) on the coefficient of flow rate (C_{dc}). To achieve this goal, the relationships between (C_{dc}) and (h/P) for constant height of model (P = 150 mm) and various diameters of crest (D = 50, 75 and 110 mm) are shown in Figure 13. Figure13 clearly demonstrates that the weir model of crest diameter (D = 50 mm) offers high flow rate coefficient (C_{dc}) values compared to those models having larger diameters of crest for all tested model heights which can be attributed to the fact that the smaller diameter of crest allows the flow jet to pass over the weir more easily and freely. Noori and Aaref (2017) and Aaref (2016) and Noori (2020) in their studies on circular crested weirs have achieved a similar outcome conclusion. From the present study, one may achieve a conclusion that the highest coefficient of flow rate values can be achieved when the height of the model (P) = 150 mm and diameter of crest (D) = 50 mm, hence, the dimensionless ratio of (D/P) = 0.33.

The numerical modeling results of head above crest and discharge coefficient of model No. 1 (best performing weir model with (P) = 150 mm and (D) = 50 mm) are compared with those experimentally obtained in Table 2 showing the percentage errors in head above crest and the discharge coefficient. Table 2 clearly shows that the percentage error in the head above crest (h) is ranging between 0.42% and 3.89% while, the percentage error in discharge coefficient (C_{dc}) is ranging between 0.64% and 6.13%.

The overall mean percentage error of all results of the different weir models is found equal to 4.24% for head above crest and 6.80% for discharge coefficient. These percentages of error are quite acceptable in engineering modeling.

Table (2): Comparison of numerical modeling results with those of experimental ones for model No. 1 (P = 150 mm and D = 50 mm)

Run No.	P (mm)	D (mm)	Experimental		Numerical		Error %	
			h (mm)	C_{dc}	h (mm)	C_{dc}	h (mm)	C_{dc}
1	150	50	32.1	0.7751	33.00	0.7436	2.80	4.06
2	150	50	45.2	0.7796	45.00	0.7848	0.44	0.67
3	150	50	51.5	0.7842	51.28	0.7892	0.42	0.64
4	150	50	65.5	0.8011	63.93	0.8308	2.39	3.70
5	150	50	73.5	0.8200	71.31	0.8580	2.98	4.63
6	150	50	83.2	0.8375	79.96	0.8889	3.89	6.13
7	150	50	95.1	0.8583	92.10	0.9006	3.15	4.92

It was concluded previously that model diameter of crest (D = 50 mm) and height of model (P = 150 mm) passes higher discharges and offers better performance compared with other models. Also, it is interesting to examine the impact of the relative head over crest ratio (h/D) on the coefficient of flow rate. The relationships between (C_{dc}) and (h/D) for constant diameter of crest (D = 50 mm) and various heights of model are illustrated in Figure 14. Figure 14 shows that the values of (C_{dc}) rise with the rise of (h/D) values for all heights of models and the model of height (P) = 150 mm offers higher values of (C_{dc}) and performs better compared with the other models.

To show the combined effect of both (h/P) and (h/D) on the coefficient of flow rate (C_{dc}), fifty-four tests are invested to show the variation of (C_{dc}) with both (h/P) and (h/D). Experimental results of the nine weir models of circular crests are used as data for the regression program (SPSS) obtaining the following equation:

$$C_{dc} = 0.623 + 0.288\left(\frac{h}{P}\right) + 0.020\left(\frac{h}{D}\right) \quad (8)$$

with a coefficient of correlation (R) = 0.88.

The predicted values of (C_{dc}) obtained from Eq. (8) are plotted with those experimentally observed in Figure 15. The validation of Eq. (8) may be justified via investing the equation of Mean Percentage Error (MPE) as (Noori, 2020):

$$MPE = \frac{100}{N}\sum_{i=1}^{N}\frac{(C_{dc})_{predicted}-(C_{dc})_{observed}}{(C_{dc})_{observed}} \quad (9)$$

Nine data results (N = 9), one from the experiments of every model, are not invested for training Eq. (8) but used for the validation of coefficient of flow rate in Eq. (9). The MPE value for the determination of (C_{dc}) is obtained in the range 0 to ± 0.66% for all models. It is important to mention that Eq. (8) is proposed for the (h/P) values between 0.12 and 0.63 and the (h/D) values between 0.29 and 1.90.

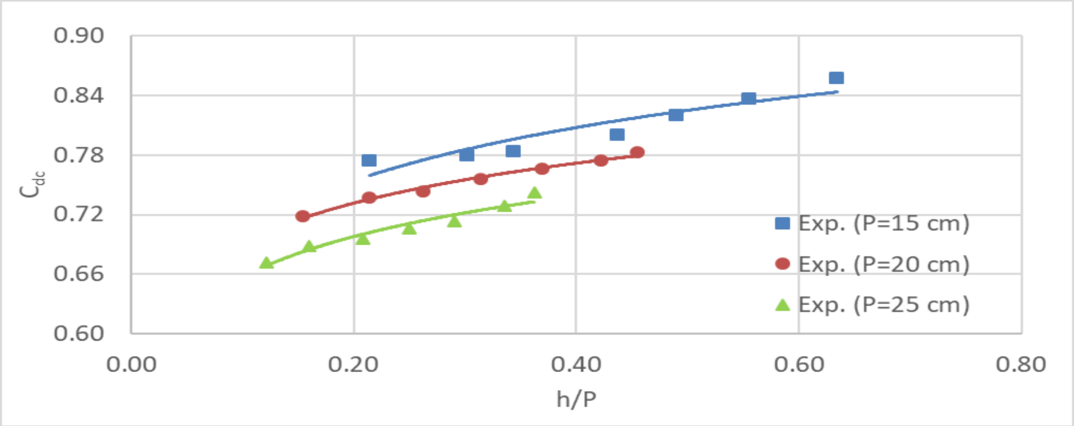

Fig. (10): Relation between (C_{dc}) and (h/P) for D = 50 mm and various model heights

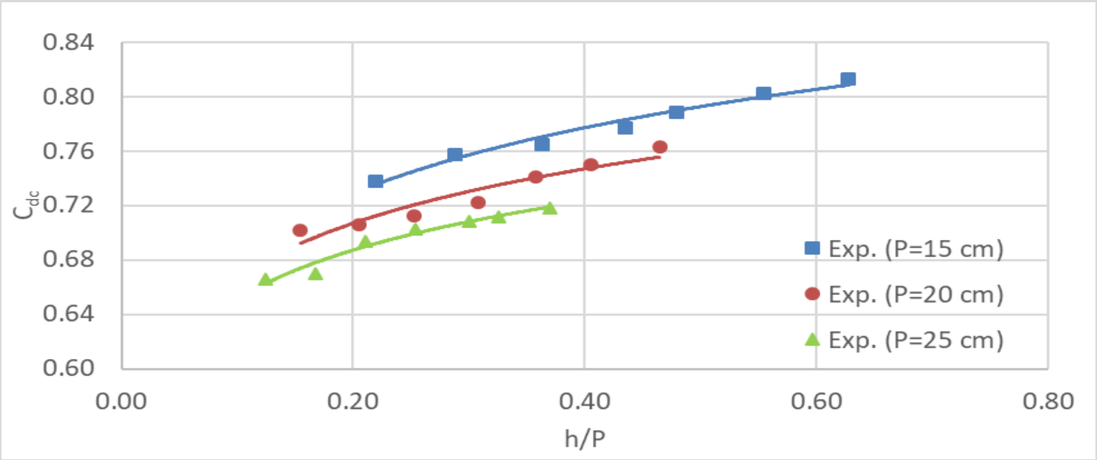

Figure (11): Relation between (C_{dc}) and (h/P) for D = 75 mm and various model heights

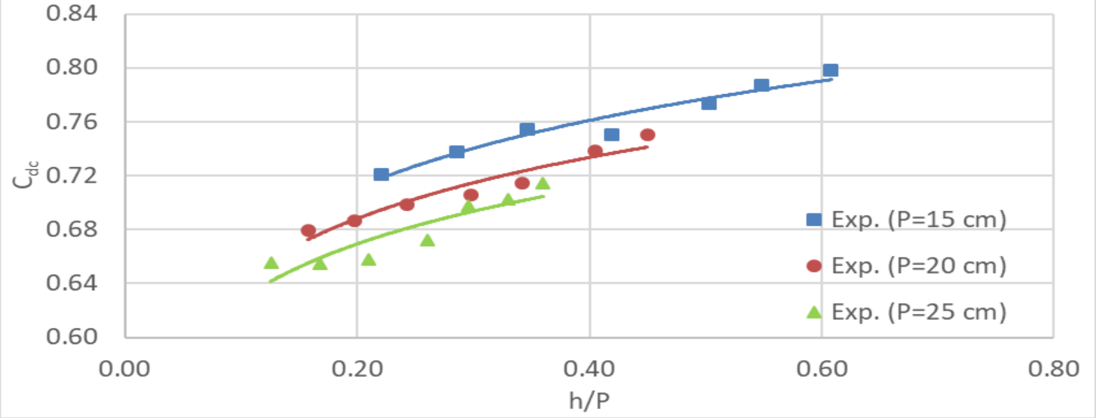

Fig. (12): Relation between (C_{dc}) and (h/P) for D = 110 mm and various model heights

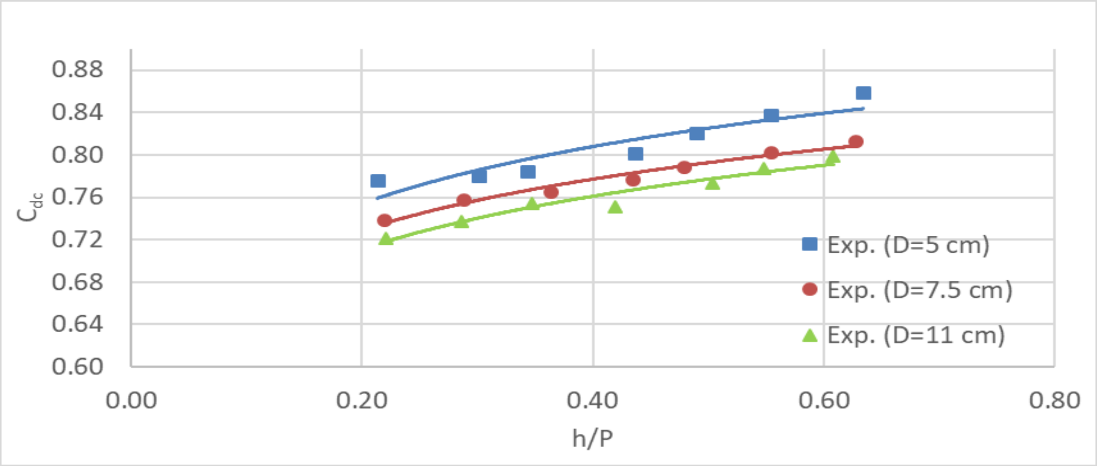

Fig. (13): Relation between (C_{dc}) and (h/P) for P = 150 mm and various diameters of crest

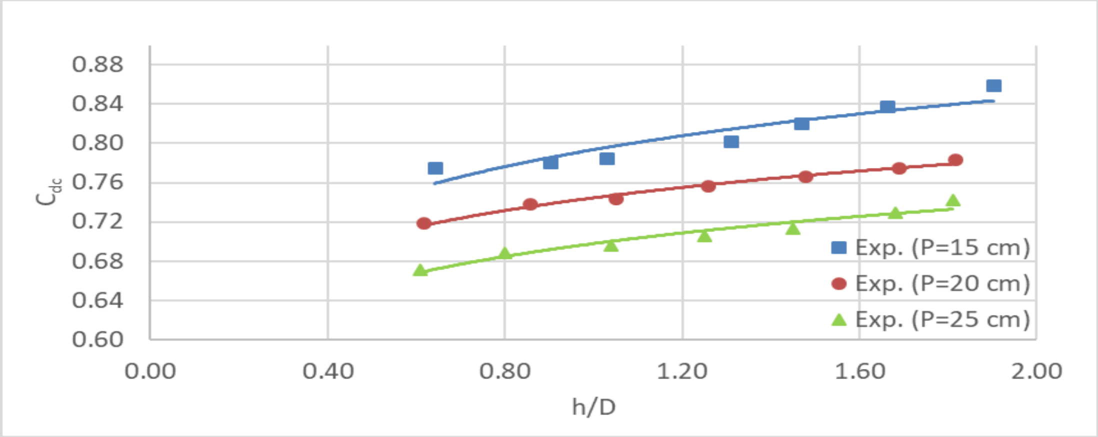

Fig. (14): Relation between (C_{dc}) and (h/D) for D = 50 mm and various model heights

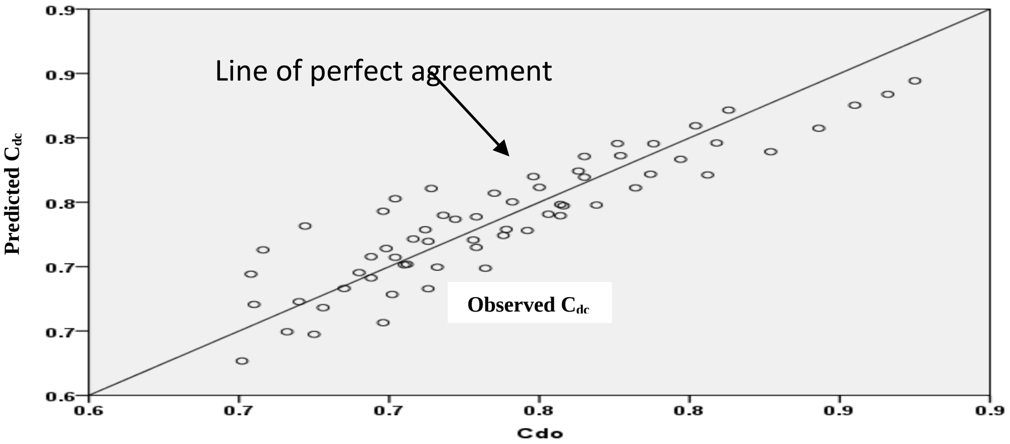

Fig. (15): Predicted values of (C_{dc}) versus those experimentally observed

4.4 Weir Efficiency

The advantage of using circular crested weirs instead of sharp crested weirs is to pass higher flow rates for the same head above crest and the same crest length. To estimate the efficiency of normal weir with circular crest, the ratio of flow rate overpassing the weir of circular crest (Q_{nc}) to that overpassing sharp crested normal weir (Q_{ns}) has to be calculated for each run. To calculate the flow rate overpassing normal weir of sharp crest (Q_{ns}), the relevant British Standard expression (British Standard Istitude, 1965) is used as:

$$Q_{ns} = \frac{2}{3}\sqrt{2g}\, C_{ds} * \; B * \; h^{1.5} \qquad (10)$$

in which, B = crest length (m), g = gravity acceleration (m/s^2), h = head of water over crest (m) and C_{ds} = coefficient of flow rate of sharp crested weir estimated by the equation:

$$C_{ds} = 0.602 + 0.075\left(\frac{h}{P}\right) \qquad (11)$$

where, P = weir height (m).

It is previously mentioned that models having diameter of crest (D) = 50 mm are passing higher flow rates compared with other models. The variations of flow rate magnification (weir efficiency) of normal weirs having cicular crests (Q_{nc}/Q_{ns}) with (h/P) are illustrated in Figure 16 depicting that (Q_{nc}/Q_{ns}) values rise with the rise of (h/P) values and the weir of low height gives higher efficiency. The values of flow rate percentage increase overpassing weirs of circular crests compared to the flow rates overpassing normal weirs of sharp crests for the same heights and widths of the channel are shown in Table 3. Table 3 is obtained for weirs having diameter of crest (D = 50 mm) and heights (P =150, 200 and 250 mm). Table 3 demonstrates that the weir of crest diameter (D = 50 mm) and height (P = 150 mm) offers flow rate percentage increase ranging between 25.41% and 32.14% giving this weir the highest efficiency and the best performance among other weir models.

Table (3): Flow rate percentages increase for weirs of crest diameter (D = 50 mm) and various model heights

Diameter of crest D (mm)	Height of weir P (mm)	% Flow rate increase	
		Minimum %	Maximum %
50	150	25.41	32.14
50	200	17.07	23.15
50	250	9.84	17.98

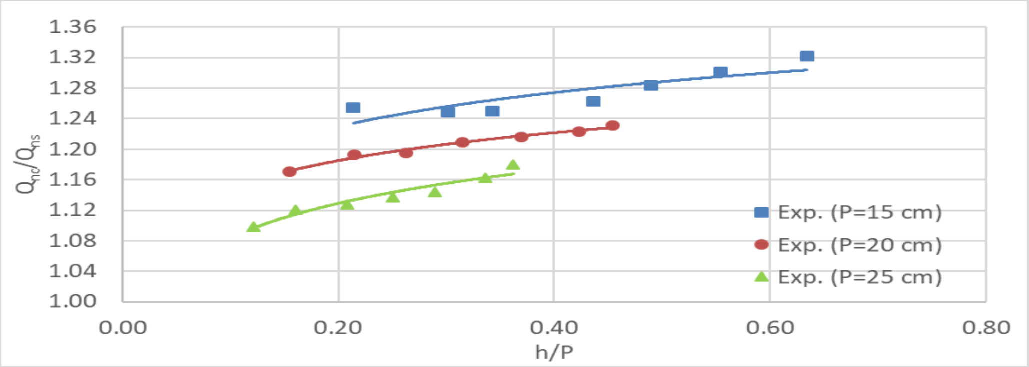

Fig. (16): Relation between (Q_{nc}/Q_{ns}) and (h/P) for D = 50 mm and various model heights

4.5 Comparison of Circular Crested Weir Results with those of Semicircular Crested Weir

The raw data of semicircular normal weirs obtained by Chilmeran (1996) and Noori and Chilmeran (2005) for semicircular crest diameter (D = 100 mm) and weir height (P = 250 mm) have been reanalysed and compared with the results of the present study for crest diameter of (D = 110 mm) and weir height (P = 250 mm) in Table 4 and Figure 17. One may realize from Figure 17 that circular rested normal weir passes higher values of overtopping flow rates for the same heads above crest. Also, it is quite clear from Table 4 that the performance of circular normal weir is much better than that of semicircular by giving higher flow rates, higher discharge coefficients and higher flow rate magnifications. The flow rate magnification of weirs having semicircular crests (ratio of semicircular crest weir flow rate (Q_{nsc}) to that of sharp crested weir (Q_{ns}), i.e. (Q_{nsc}/Q_{ns})) is ranging between 1.0159 and 1.0793. This means that the percentage increase in flow rates of semicircular weir is ranging between 1.59% and 7.93%, while the increase in flow rate percentage obtained by weirs of circular crests for the particular case (D = 110 mm and P = 250 mm) is ranging between 7.16% and 13.59% which demostrates that normal weirs of cicular crests overpass higher flow rate capacity and perform much better compared to normal weirs of semicircular crests. From the above evidence, it is quite clear that circulating the crest of normal weir rises the flow rate capacity and offers better behavior compared with weirs of some other crest shapes.

Table (4): Comparison of the present study results with those of semicircular weir ones.

Semi-circular crested weir (Noori and Chilmeran,1996)						Circular crest weir (Present study)					
D (mm)	P (mm)	h (mm)	Q_{nsc} (l/s)	C_{dsc}	$\frac{Q_{nsc}}{Q_{ns}}$	D (mm)	P (mm)	h (mm)	Q_{nc} (l/s)	C_{dsc}	$\frac{Q_{nc}}{Q_{ns}}$
100	250	24.4	2.09	0.6190	1.0159	11	25	3.15	3.25	0.6552	1.0716
100	250	40.4	4.49	0.6242	1.0165	11	25	4.20	4.99	0.6545	1.0648
100	250	55.4	7.28	0.6302	1.0187	11	25	6.50	9.87	0.6723	1.0817
100	250	81.9	13.71	0.6603	1.0538	11	25	8.25	14.75	0.7025	1.1208
100	250	87.8	15.63	0.6782	1.0793	11	25	9.00	17.09	0.7145	1.1359

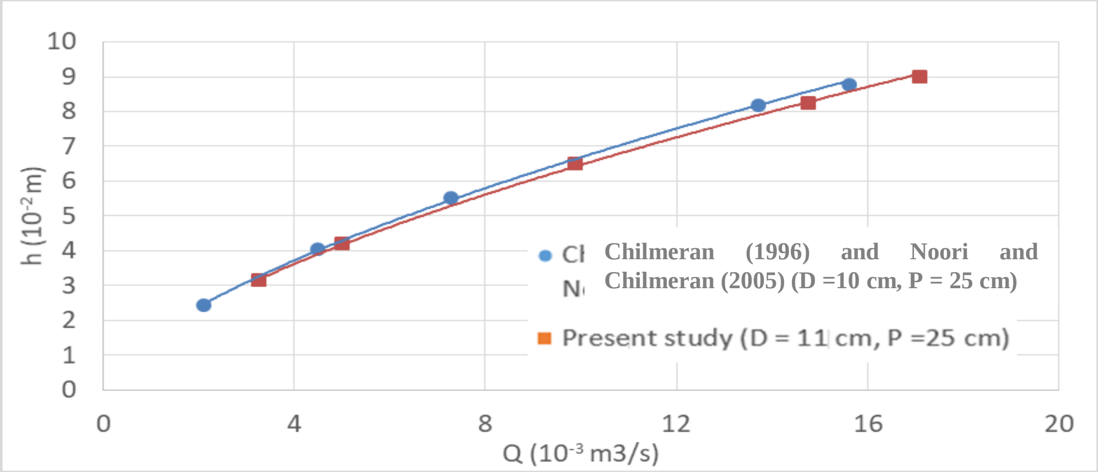

Fig. (17): Comparison of circular crested weir results with those of semicircular crested weir

5. SUMMARY AND CONCLUSIONS

The present study simulates numeriscally the behavior of weirs with circular crests using ANSYS CFX package in which tetrahedrons mesh type is used with a maximum total number of elements of 1932301. To verify the numerical model results, the experimental part of the present study is conducted including the tests of nine physical weir models in which the height of the model is varied as (P) = 150, 200 and 250 mm and for every height of model the crest diameter is varied as (D) = 50, 75 and 110 mm. The results are obtained within the limitations: $0.12 \leq h/P \leq 0.63$ and $0.29 \leq h/D \leq 1.9$ and the flow in the approach channel was turbulent for the range of Reynolds number between 3720 and 28220.

The numerical simulation ANSYS CFX software is found highly capable to simulate the circular crested normal weirs and their hydraulic performance. Comparison between numerical modeling results and the results of physical models showed that the mean percentage error in head above crest (h) equals to 4.3% and the mean percentage error in estimating discharge coefficint (C_{dc}) equals to 6.8% for all tests on circular crested normal weirs. Records of water surface profiles showed quite good agreements between those obtained experimentally and the outcome results of numerical modeling. The maximum distances (X) are observed within the rang 3.1 h and 4.6 h representing the nearest pointer gauge locations upstream crest center for accurate measurements of upstream water head over crest. It is also found that the coefficient of flow rate (C_{dc}) value rises with the rise of (h/P) value for all tested models. The smaller height of model gave higher (C_{dc}) values for constant diameter of crest while for constant height of model, weir model of small diameter of crest offered higher (C_{dc}) values. The highest coefficient of flow rate is observed when the ratio of (D/P) equals to 0.33.

A simple empirical equation is proposed for the prediction of (C_{dc}) as a function of (h/P) and (h/D) with a coefficient of 0.88. The mean percentage error in computing (C_{dc}) was between 0 and ± 0.66% for all models of various diameters of crest and various heights. The flow rate maginification (Q_{nc}/Q_{ns}) is found rising with the rise of (h/P) values for constant diameter of crest and different hights of model. A model of diameter of crest = 50 mm and height = 150 mm offerred the higher range of flow rate percentages increase between 25.41% and 32.14% compared to weirs of sharp crests. Comparison of circular crested weir results with those of semicircular crested weir confirms that the weir of cicular crest overpasses higher flow rate values for the same heads over crest. It is quite clear that weirs of cicular crests give higher coefficinets of flow rate and higher flow rate magnifications and as a result circular crested weir offers better hydraulic performance compared to semicircular crested weir.

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