January - February 2020
ISSN: 0193 - 4120 Page No. 1829 - 1838

Hydraulic Characteristics of Square Labyrinth Weirs with Sharp or Semi-Circular Crest

Ruqiya Abed Hussain, Fadya Saadi Klak
Civil Engineering Dept. – University of Tikrit

Article Info
Volume 82
Page Number: 1829 - 1838
Publication Issue:
January-February 2020

Article History
Article Received: *14 March 2019*
Revised: *27 May 2019*
Accepted: *16 October 2019*
Publication: *09 January 2020*

Abstract:
Labyrinth weirs have been of interest to engineers and researchers for many years because of their hydraulic behavior. This paper present an experimental study to define the hydraulic characteristics of flow over square labyrinth weirs with semi-circle and sharp crest, by using range of experiments. and compare their efficiency with conventional weirs(Suppressed rectangular weir) with same shape of crest, three different heights (p) for each one of these weirs were used (25,20 and 15) cm for each of the above cases , seven different discharge were passed. The overall tests in this study were 84.

Data obtained from laboratory and according to the result parameters from the dimensional analysis of the factors affecting on the flow over the labyrinth weirs, parameters were plotted, it was found that the labyrinth weirs gave better performance efficiency when compared to conventional weirs(Suppressed rectangular weir) for their passage and capacity high discharge. Also the results show that the coefficient of discharge (Cd) with constant height of weir have a high value in low values of H/P and decrease gradually with increase this ratio , where gave the square labyrinth weirs with semi-circle the highest value of the discharge coefficient reached (2.55) . In additional to shape of crest weir has great effect on (Cd) and on performance efficiency , where the labyrinth weir with semi -circular crest gave high performance from sharp crest.

Keywords: *weir, labyrinth weir, structure Hydraulics, Suppressed rectangular weir*

Notations
The following symbols are used in this paper:
b ……. Channel width (L)
Cd……Discharge coefficient of weir
g …….. acceleration gravity (L/T2)
H ….Height of the water upstream above the crest of the labyrinth weir (L)
Hsw ……Depth of water above the Standard triangle weir (L)
L ….. Effective length of labyrinth weir(L)
p…….Height of weir above channel bed (L)
q …….Water discharge per unit width (L2 /T)
QCs ……Discharge over Suppressed rectangular weir with semi-circular crest (L3/T)
QLs…….Discharge over Square labyrinth weir with semi-circular crest(L3/T)
w ……. Width of a single labyrinth weir cycle (L)
ρ …….. Mass density of water((M/T3)
μ…….Dynamic viscosity of water (M/LT)

I. INTRODUCTION

Labyrinth weirs provide an effective means to increase the spillway discharge capacity of dams and are often considered for regeneration projects required due to an increase in expected flood inflow to the reservoir of an existing dam. Since their discharge capacity is directly proportional to the crest length, several types have been developed with the purpose to increase the length of the latter. In recent years, extensive researches focused on the influence of geometric and hydraulic parameters on the hydraulic behavior of labyrinth weirs, particularly on the discharge capacity, Several previous studies were conducted to determine the characteristics of flow over rivers and canals.

The first rational approach for studying the flow over Labyrinth weirs was published by Taylor[1] which performed several experimental model tests on different configurations of labyrinth weirs in order to develop a design method. As part of his research, the effects of nappe interference on the labyrinth weir performance was studied, In this research the vertical aspect ratio (w/P) to predict the effects of nappe interference was used, where w is width of a single labyrinth weir cycle and P is weir height. The conclusions concerns that when(w/P) is large, the effects of nappe interference can be effectively eliminated. However when (w/P) is small, nappe interference becomes a determining factor in labyrinth weir performance. Lux[2] developed the hydraulic performance of Labyrinth weirs from the data obtained from flume studies and site specific models. In this study, the combination of dimensional analysis and experimentation were used to develop an equation for the discharge of the labyrinth weir, also the discharge coefficient for triangular and trapezoidal plan forms with the sharp-crested and quarter round labyrinth weir was defined. Cassidy et al[3] performed a brief study on the Boardman labyrinth spillway and found that the calculated discharge coefficients determined from extrapolated results from (Hay and Taylor ,1970) were not consistent with their model study. They found differences in discharge capacity between 20-25% at high heads. Amanian[4] tested eleven linear weirs and eight half-round triangular labyrinth weirs in a channel, including oblique labyrinth weirs. The conclusions show that the discharge efficiency of labyrinth weirs declines as HT increases (due to submergence and nappe interference), also, the efficiency can be increased with a half-round crest shape (relative to quarter-round, flat, or sharp crest shapes). Nuri and Hayawi[5] investigate the characteristics of flow over long labyrinth weir consisting of two symmetrical triangles from the top view for two angle (30,40) from side wall of weir and three heights (10 ,15 and 20) cm. The results conclude that the weirs with small-angle and lower height give better performance and greater discharge .

Kocahan and Taylor[6] suggested that the labyrinth-shaped weir allows more discharge than a regular ogee weir at the beginning of a flood and doesn't depend on "mechanical equipment or human intervention" (i.e., passive control). Increasing the weir length (and subsequently Q) of an existing spillway channel by replacing a linear weir with a labyrinth weir represents, in most cases, a more economical and efficient alternative relative to widening the spillway channel. Emiroglu et al.[7] studied the performance of the labyrinth side weirs and presented coefficient of discharge curves in a simplified way as compared to previous investigators. Crookston[8] makes labyrinth weirs with an effective alternative for use in spillway rehabilitation projects. The longer weir length, and subsequent increased discharge efficiency, means that for a given upstream pool elevation, the labyrinth weir will produce a larger discharge relative to a linear weir. Bilhan et al [9] studied discharge coefficients were experimentally determined for sharp crested trapezoidal labyrinth weirs of varying side wall angle (α). The experimental results of 21 physical models were used to develop a hydraulic design and analysis method for labyrinth weirs. The present research primarily aims at evaluating various characteristics of a flow-over labyrinth weir by conducting experimentations at wider range of values for important parameters.. Anderson and Tullis[10] used laboratory-scale physical models to compare the hydraulic efficiency of the Piano Key (PK) weir design with that of a geometrically similar rectangular labyrinth weir, with and without sloping floors installed in the inlet and outlet keys. The test data showed that the (PK) weir was more efficient than the geometrically comparable rectangular labyrinth weir, a fact likely attributable to a reduction in entrance losses associated with the (PK) weir inlet key geometry.

II. DIMENSIONAL ANALYSIS

The dimensional analysis is a function of many variables involved in the calculation of the discharge passing over the studied weirs, which can be put in the following formula :

January - February 2020
ISSN: 0193 - 4120 Page No. 1829 - 1838

$q = \phi(H, p, g, \rho, \mu)$ ……………………………….(1)

The relationship between all variables is:

$\phi(q, H, p, g, \rho, \mu)=0$ ………………………….. (2)

Where:-

- q ---- Water discharge per unit width (L2/T)
- H ----- Height of the water upstream above the crest of the labyrinth weir (L)
- p ----- Height of weir above channel bed (L)
- g ------ acceleration gravity (L/T2)
- ρ ------ Mass density of water((M/T3)
- μ. ------ Dynamic viscosity of water (M/LT)

From the variables mentioned above, it can be inferred numbers of dimensionless parameters which represent the conditions of flow by using the theory of (π's-Theorem) Swamee[11]

$\pi1= q, H, \mu, p$

$\pi2= q, H, \mu, g$

$\pi3= q, H, \mu, \rho$

In the post-analysis we get:

$\pi1=\frac{H}{p}$ $\pi2=\frac{q^2}{gH^3}$ $\pi3=\frac{\mu}{\rho q}$

Therefore:-

$$\frac{q^2}{gH^3} = \phi_3\left(\frac{H}{p}, \frac{\mu}{\rho q}\right) \quad \ldots\ldots(3)$$

By taking the square root of the left side, the equation becomes:

$$\frac{q}{\sqrt{g}H^{1.5}} = \phi_4\left(\frac{H}{p}, \frac{\mu}{\rho q}\right)$$

As notes that Π_3 represents the number of Reynolds (Re), that its effect on flow can be neglected only at very few depths above the weir (Boss, 1989) [12]

After neglecting Reynold 's number, the equation above will be as follow:

$$\frac{q}{\sqrt{g}H^{1.5}} = \phi_5\left(\frac{H}{p}\right) \quad \ldots\ldots(4)$$

III. Laboratory Channel

Experimental tests were carried out in a horizontal and rectangular laboratory channel in the field of environmental engineering, Tikrit University. The dimensions of this channel are 6m length, 30 cm width and 40cm height. This channel is equipped with water by a hydraulic pump, the maximum discharge of this pump is 22l/s and controlled by a valve which can be changed according to the required discharge.

IV. Experimental Work and Results Analysis

All experiments were carried out on square labyrinth weirs models from the upper perspective having semi-circular and sharp crest , in addition to conventional weirs (Suppressed rectangular weir models) having same shape of the crest of the labyrinth weirs models (for comparison purposes). Figs. (1-4) shows samples of weirs used in this study before and after test .For each model, three different heights (p=15, 20 and 25cm) were used. All models were made by using fiberglass with thickness 1 cm , the head over the weir models was measured by using a point gauge.

Figure.1: Square labyrinth weir with semi-circular crest

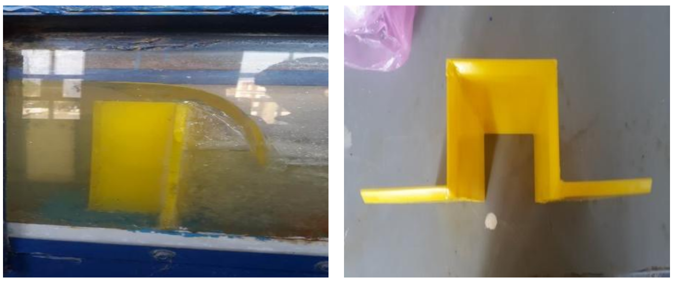

Fig. (2) Square labyrinth weir with sharp crest

Fig. (3) Suppressed rectangular weir with semi-circular crest

Fig. (4) Suppressed rectangular weir with sharp crest

The study models of weirs were performed by separated it with two groups, has been used (84) discharges by seven runs for each of the twelve models. The discharge of the channel was measured by using a standard triangle weir, which was fixed at the end of the channel as shown in Fig. (5). This weir was made by 1cm thickness plastic material plate.

Fig. (5) standard triangle weir

The discharge over labyrinth weir can be determined by application of the Rehbook formula (Bos, 1989) [12]

$$Q = \frac{2}{3}\ Cd\ \sqrt{2g} \times L \times (H)^{\frac{3}{2}} \quad \text{.....................(5)}$$

Where:

Q =discharge over a labyrinth weir

Cd =coefficient of discharge for labyrinth weir

L = effective length of labyrinth weir

H = head of the water upstream weir

g = ground acceleration

Head of water over labyrinth weir was measured for different values of discharge. The model of linear weir is also tested in the same flume for the purpose of comparison.

The actual discharge of flow for all tests was measured by standard triangular weir. The equation of this weir is :-

$$Q_{sw} = 0.0132\ (H_w)^{2.5622} \quad \text{......................... (6)}$$

where Qsw is the discharge over a Standard triangle weir (L/s) and Hw is the water depth above the Standard triangle weir (cm)

The discharge coefficient Cd can be calculated as follows:

$$Cd = \frac{Q_{(act.)}}{Q_{(theo.)}} \quad \text{..(7)}$$

Tables (1) to (5) shows all of these data.

Table (1) Experimental and Calculated Data for Square labyrinth weir with semi-circular crest

Test No.	H_{sw} (mm)	H (mm)	$Q_{(act.)}$ l/sec)	$Q_{(theo.)}$ (l/sec)	C_d	H/P
P=25cm						
1	59.4	6.8	1.268	0.497	2.55	0.027
2	75.9	11.5	2.376	1.093	2.173	0.046
3	84.1	14.8	3.091	1.595	1.938	0.059
4	90.9	18.4	3.772	2.211	1.706	0.074
5	98.1	22.3	4.586	2.95	1.555	0.089
6	106.8	21.4	4.162	2.773	1.501	0.086
7	110.1	28.1	6.164	4.173	1.477	0.112
P=20cm						
1	39.5	3.7	0.446	0.199	2.24	0.0185
2	64.1	9.1	1.545	0.769	2.01	0.0455
3	76	12.9	2.384	1.298	1.837	0.065
4	91	19.3	3.783	2.375	1.593	0.097
5	96.8	22.2	4.432	2.93	1.513	0.111
6	106.2	27	5.62	3.93	1.43	0.135
7	110.9	29.4	6.279	4.466	1.406	0.147
P=15cm						
1	49.7	7.5	0.803	0.575	1.797	0.05
2	66.2	11.7	1.879	1.121	1.677	0.078
3	80	15.6	2.721	1.726	1.577	0.104
4	90	20	3.677	2.506	1.467	0.133
5	97.2	24.1	4.479	3.314	1.352	0.161
6	107.2	29.2	5.756	4.42	1.3	0.195
7	111	31.1	6.294	4.859	1.295	0.207

TEST Engineering & Management

January - February 2020
ISSN: 0193 - 4120 Page No. 1829 - 1838

Table (2) experimental and calculated data for square labyrinth weir with sharp crest

Test No.	H_{sw} (mm	H (mm)	$Q_{(act.)}$ (l/sec)	$Q_{(theo.)}$ (l/sec)	C_d	H/ P
P=25cm						
1	61.9	10.5	1.409	0.953	1.478	0.042
2	68.8	18.6	1.848	2.247	0.822	0.0744
3	79.1	23.5	2.642	3.191	0.828	0.094
4	88.6	28.8	3.533	4.33	0.815	0.1152
5	100	35.6	4.817	5.951	0.809	0.1424
6	107.1	39.7	5.742	7	0.82	0.1588
7	111.1	42.8	6.308	7.844	0.804	0.1712
P=20cm						
1	46.1	9.1	0.662	0.769	0.86	0.0455
2	62.6	15.6	1.455	1.726	0.843	0.078
3	78.2	23	2.565	3.09	0.83	0.115
4	89.9	30.2	3.667	4.649	0.789	0.151
5	97.6	33.6	4.526	5.456	0.829	0.168
6	104.5	39.8	5.392	7.034	0.766	0.199
7	111.1	44.1	6.308	8.204	0.769	0.221
P=15cm						
1	43.8	8.2	0.581	0.658	0.883	0.0547
2	59	14	1.248	1.467	0.851	0.093
3	80.1	24.1	2.728	3.314	0.823	0.161
4	89.2	29.3	3.594	4.443	0.809	0.195
5	100.4	38.3	4.866	6.64	0.733	0.255
6	106	4.3	5.593	7.71	0.725	0.282
7	111.1	46.1	6.308	8.769	0.719	0.307

Table (3) experimental and calculated data for suppressed rectangular weir with sharp crest

No.	H_{sw} (mm)	H (mm)	$Q_{(act.)}$ (l/sec)	$Q_{(theo.)}$ (l/sec)	C_d	H/P
P=25cm						
1	73.6	11.9	2.1965	1.150	1.91	0.048
2	82.7	16.3	2.961	1.844	1.606	0.065
3	89.3	18.1	3.605	2.157	1.67	0.072
4	96.5	22.5	4.397	2.989	1.371	0.09
5	102.5	27.5	5.132	3.952	1.299	0.108
6	108.4	31.3	5.923	4.906	1.207	0.125
7	109.7	32.3	6.106	5.119	1.193	0.129
P=20cm						
1	41.5	4.8	0.506	0.295	1.715	0.024
2	62	11.5	1.415	1.093	1.295	0.058
3	72.1	13.2	2.083	1.344	1.55	0.066
4	80.9	16.6	2.798	1.895	1.477	0.083
5	91.2	22.4	3.804	2.97	1.281	0.112
6	101.3	27.7	4.979	4.084	1.23	0.139
7	110.9	32.6	6.279	5.214	1.204	0.163
P=15cm						
1	55.5	8	1.066	0.634	1.68	0.053
2	68.7	11.4	1.841	1.078	1.71	0.076
3	77.2	14.4	2.482	1.531	1.62	0.096
4	81.2	16.8	2.825	1.929	1.46	0.112
5	89.1	20	3.584	2.506	1.43	0.133
6	97.4	24.7	4.503	3.439	1.31	0.165
7	108.8	32.3	5.979	5.143	1.163	0.215

Table (4) experimental and calculated data for suppressed rectangular weir with semi-circular crest

Test No.	H_{sw} (mm	H (mm)	$Q_{(act.)}$ (l/sec)	$Q_{(theo.)}$ (l/sec)	C_d	H/P
P=25cm						
1	53.5	6.2	0.969	0.432	2.243	0.025
2	73.9	12.8	2.219	1.283	1.73	0.051
3	83.7	17.5	3.053	2.051	1.489	0.07
4	93.5	25.1	4.055	3.523	1.151	0.1
5	100.2	29.3	4.842	4.443	1.09	0.117
6	107.7	34.5	5.825	5.677	1.03	0.138
7	110.4	36.1	6.207	6.076	1.022	0.144
P=20cm						
1	51.7	9.7	0.889	0.846	1.051	0.049
2	67.3	15.4	1.746	1.693	1.031	0.077
3	79.9	20.5	2.711	2.6	1.04	0.103
4	91	27.8	3.783	4.106	0.921	0.139
5	97.7	32.2	4.538	5.119	0.886	0.161
6	106.6	38	5.674	6.562	0.865	0.19
7	111.1	41.4	6.308	7.462	0.845	0.207
P=15cm						
1	51.8	9.7	0.893	0.846	1.056	0.065
2	64.3	14.5	1.554	1.547	1.005	0.097
3	81.1	22.4	2.816	2.969	0.948	0.149
4	91.9	28.4	3.879	4.239	0.915	0.189
5	98.9	33	4.682	5.311	0.882	0.22
6	103.7	36	5.287	6.051	0.874	0.24
7	111.3	41.5	6.337	7.489	0.846	0.277

Table (5) the efficiency of weirs

P=25cm		P=20cm		P=15cm	
H/P	Q_{LS}/Q_{CS}	H/P	Q_{LS}/Q_{CS}	H/P	Q_{LS}/Q_{CS}
0.08	1.45	0.05	1.836	0.05	1.57
0.1	1.418	0.1	1.567	0.1	1.534
0.12	1.335	0.13	1.533	0.15	1.488
0.13	1.2817	0.15	1.523	0.2	1.437

0.15	1.60	0.18	1.517	0.25	1.344
0.18	0.968	0.2	1.510	0.3	1.35

SQUARE LABYRINTH WEIR WITH SHARP CREST

EFFECT OF (H /P) ON DISCHARGE COEFFICIENT (CD)

After compute discharge coefficient by using equation (Eq. (7)). The discharge coefficient data (Cd) are plotted as function of the ratio (H/P) as illustrated in figures (6-8).These figures show that (Cd) is proportional to (H/P). It was noticed that (Cd) is greatly affected by the upstream head over the crest (H) , also it was noticed that the value of the discharge coefficient (Cd) is high in the low ratios of (H/ P) for all models and gradually decrease with increasing the ratio (H/P), where the model of the square labyrinth weir with semi-circular crest gave the highest value of the discharge coefficient reached (2.55), While the discharge coefficient reached its lowest value reached (0.719) for conventional weirs with sharp crest. This means that labyrinth weir is able to pass large discharges at relatively low heads compared to traditional linear weir structures.

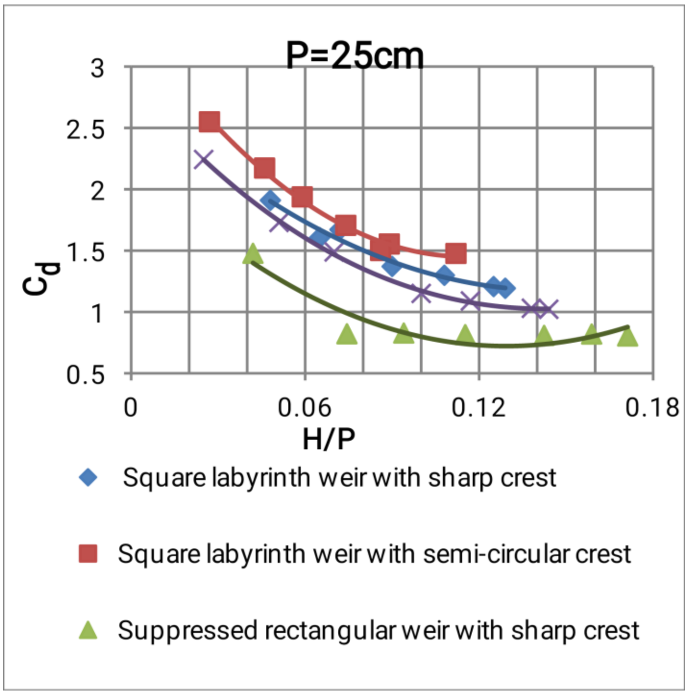

Fig. (6) Relationship between discharge coefficient (Cd) and the dimensionless value (H/P)

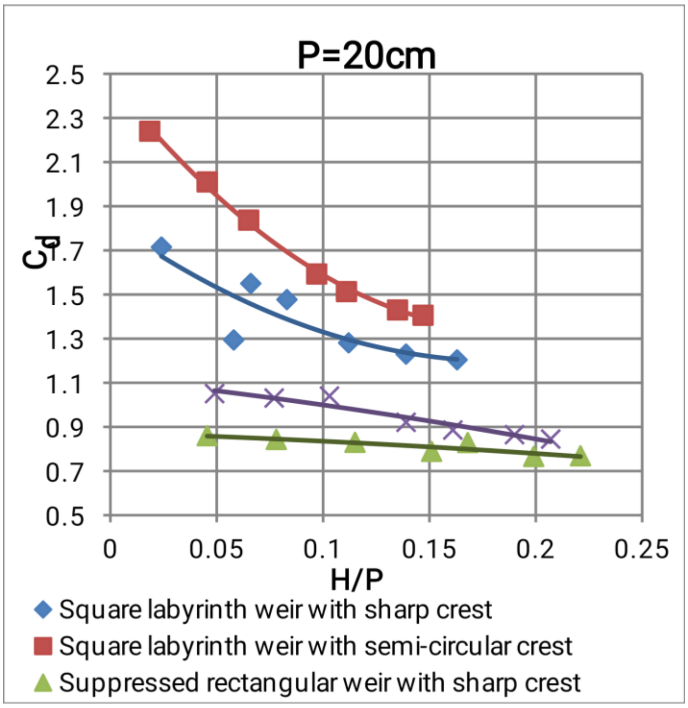

Fig. (7) Relationship between discharge coefficient (Cd) and the dimensionless value (H/P)

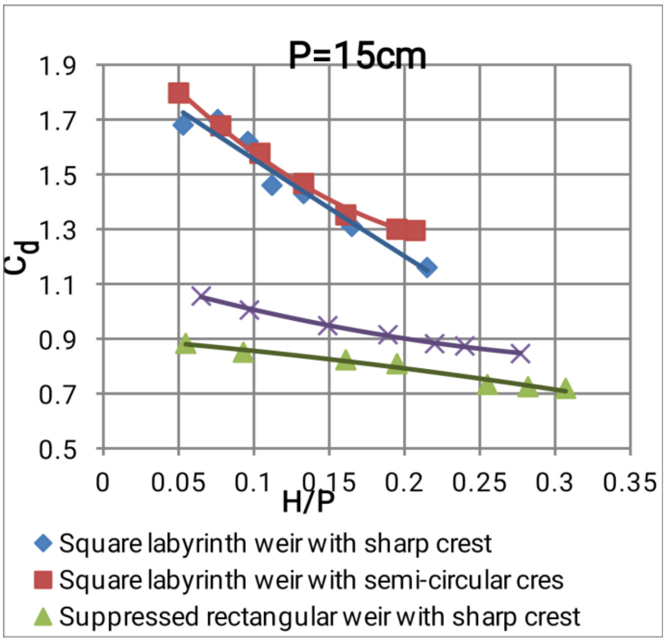

Fig. (8) Relationship between discharge coefficient (Cd) and the dimensionless value (H/p)

THE RELATIONSHIP BETWEEN (Qact) WITH (H/P) AND (CD¬)

The relationship between the actual discharge (Qact) and the ratio (H/P) was plotted. It is apparent from the results in Figs. (9-15). The shape of this relationship is directly proportional if the height is

January - February 2020
ISSN: 0193 - 4120 Page No. 1829 - 1838

stabilized and the weir type is changed or vice versa, and for any value to ratio (H/P) noted that discharge capacity for the square labyrinth weirs with semi-circular or sharp crest is higher than the Suppressed rectangular weirs (the value of the discharge coefficient(Cd) is high in the low ratios of (H/ P) for all models and gradually decrease with increasing the ratio (H/P), where the model of the square labyrinth weir with semi-circular crest gave the highest value of the discharge coefficient reached (2.55), while the discharge coefficient reached its lowest value reached (0.719) for conventional weirs with sharp crest. This indicates that the ratio (H/P) is affected by the type of weir and shape of the crest that would influence the behavior and results in curves shown , while noticed that (Qact) inversely proportional to (Cd) in Figs. (16-18) where the value of the coefficient is high when the low discharge and gradually decrease as the discharge increases, this is due to the fact that in the case of a few discharges there is a smooth flow of water that is good.

PERFORMANCE OF WEIRS

Referring to the figures (9,10and 11) that the performance of weirs was found as shown in table (5). For the comparison of square labyrinth weirs performance with hydraulic performance of Suppressed rectangular weirs variation of (QLs/QCs) with H/p was considered, Fig.(19). It was observed that the (Qls/Qcs) with H/p value is above 1.00 where the labyrinth effect is prominent, because labyrinth weirs can pass large flows at comparatively low heads. And all the percentages of efficiency more than one.this study shows that the square labyrinth weirs are hydraulically more efficient than the Suppressed rectangular weirs from the perspective of the discharge capacity and ease of construction.

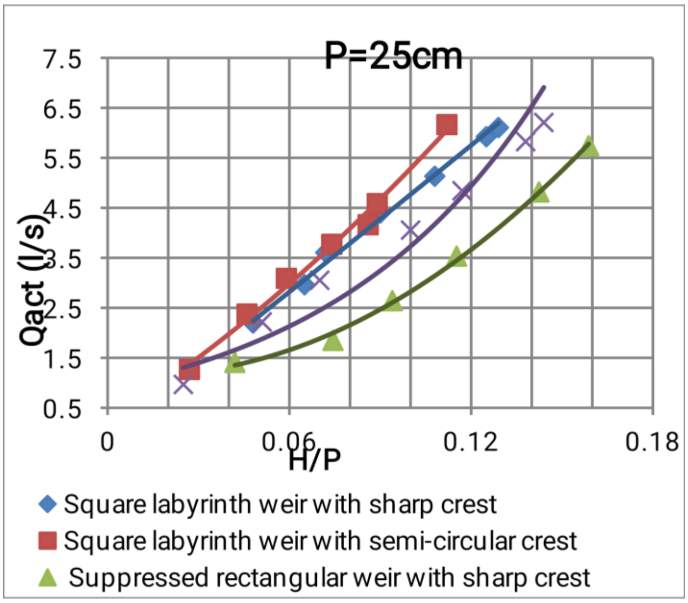

Fig. (9) Relationship between actual discharge (Qact) and the dimensionless value (H/P)

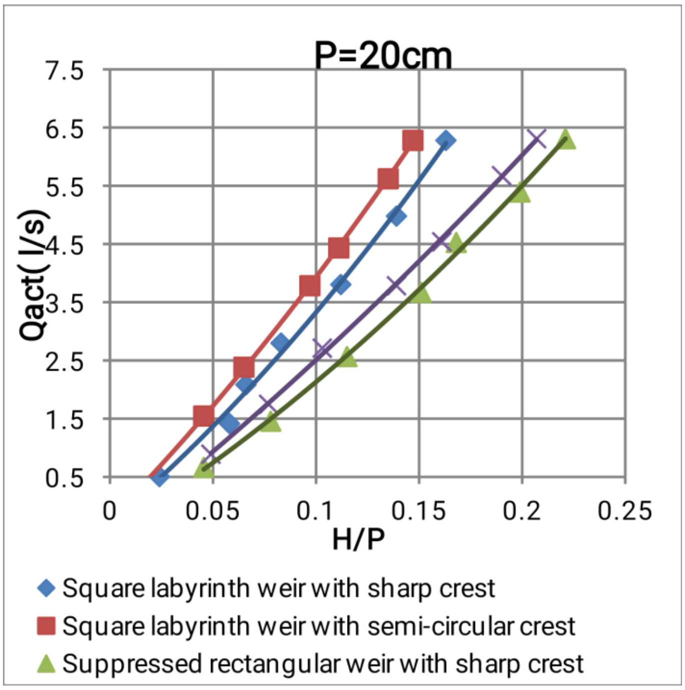

Fig. (10) Relationship between actual discharge (Qact) and the dimensionless value (H/P)

January - February 2020
ISSN: 0193 - 4120 Page No. 1829 - 1838

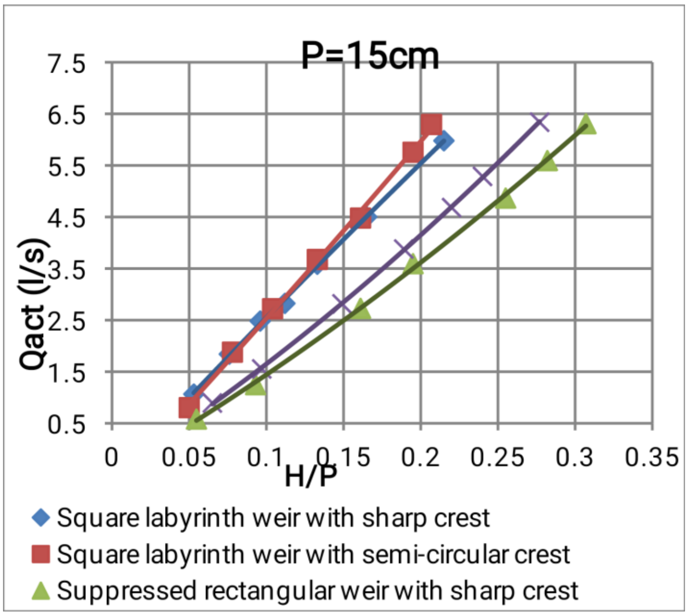

Fig. (11) Relationship between actual discharge (Qact) and the dimensionless value (H/P)

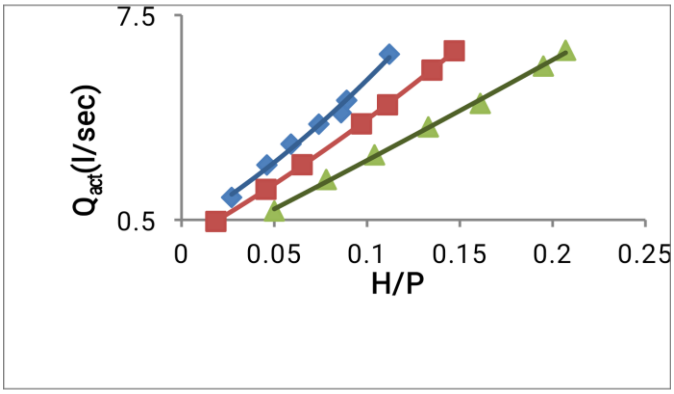

Fig. (12)Variation of actual discharge (Qact) with head to weir height (H/P) for Square labyrinth weir with semi-circular crest

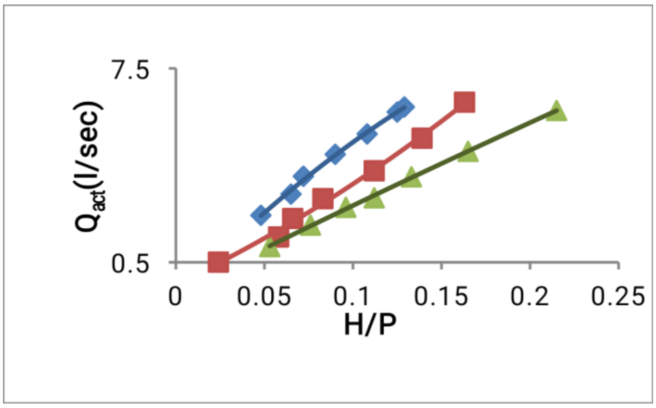

Fig. (13)Variation of actual discharge (Qact) with head to weir height (H/P) for Square labyrinth weir with sharp crest

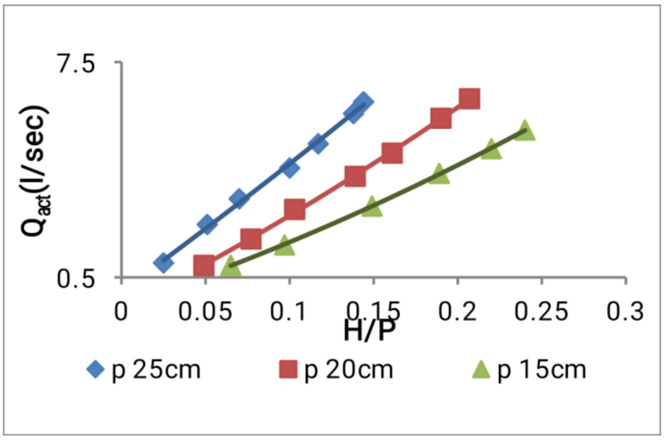

Fig. (14)Variation of actual discharge (Qact) with head to weir height (H/P) for Suppressed rectangular weir with semi-circular crest

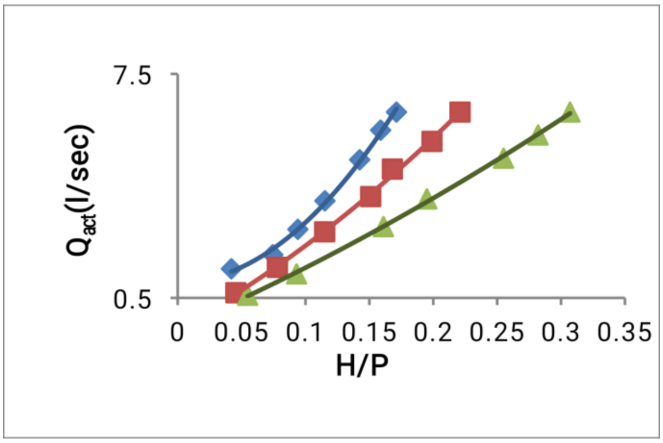

Fig.(15) Variation of actual discharge (Qact) with head to weir height (H/P) for Suppressed rectangular weir with sharp crest

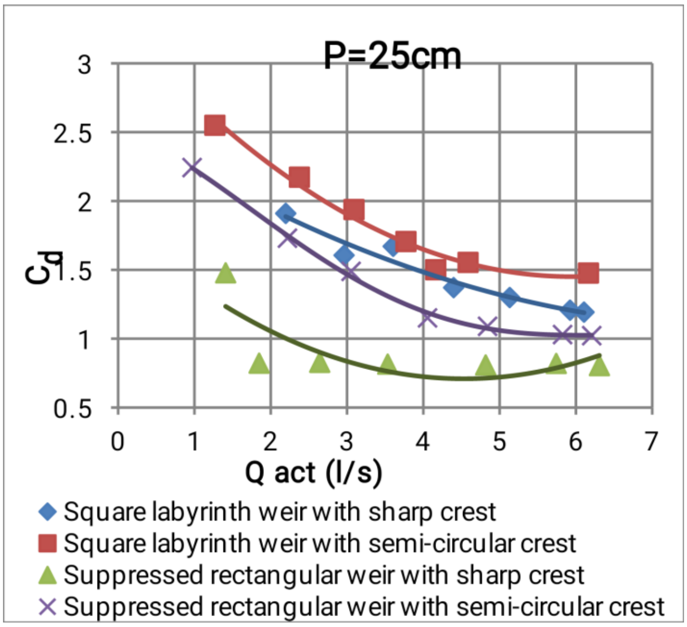

Fig. (16) Variation of discharge coefficient (Cd) with actual discharge (Qact)

January - February 2020
ISSN: 0193 - 4120 Page No. 1829 - 1838

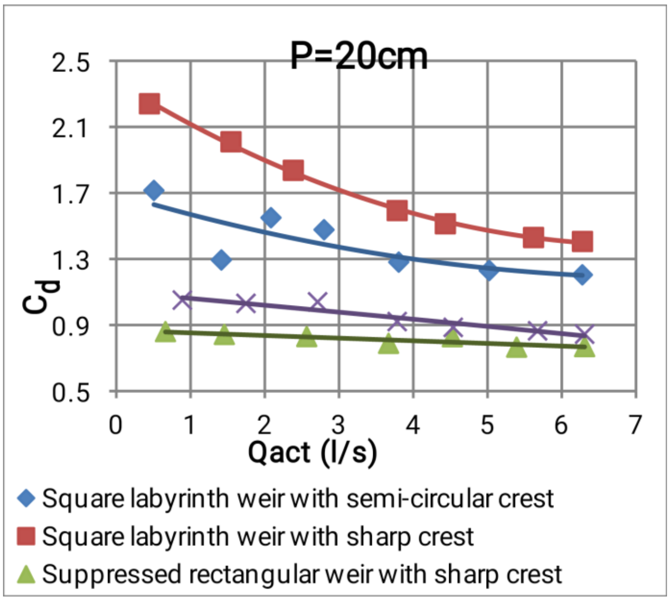

Fig. (17) Variation of discharge coefficient (Cd) with actual discharge (Qact)

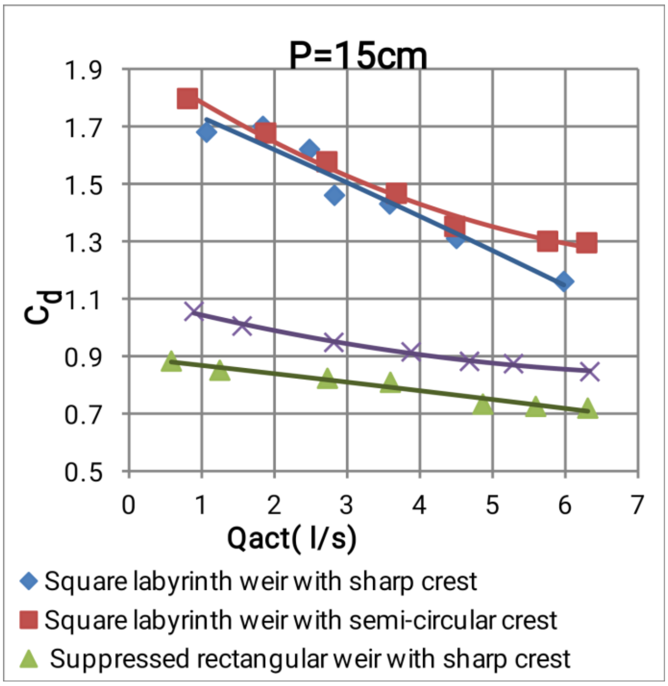

Fig.(18)Variation of discharge coefficient (Cd) with actual discharge (Qact)

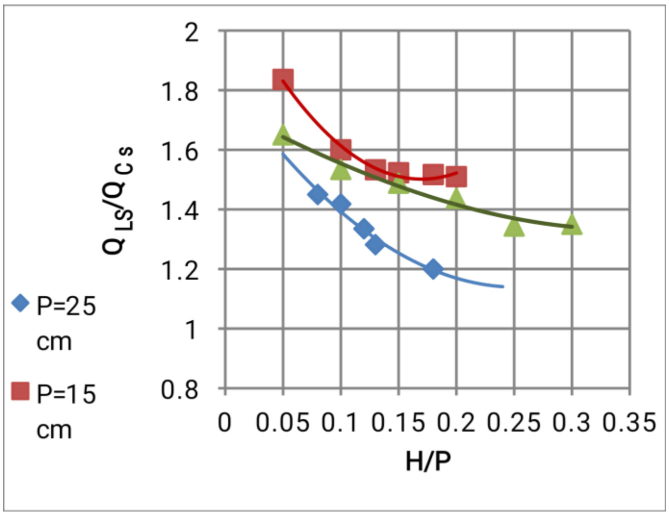

Fig. (19) Variation of ratio (Q Ls / QCs) with head to weir height (H/P)

V. CONCLUSION

Labyrinth weirs are often a favorable design option to increase flow capacity, where the Labyrinth weirs provide higher discharge capacity than Suppressed rectangular weirs (conventional weirs), with the capability to pass large flows at comparatively low heads. Depending on this experimental study, it was found that square labyrinth weir compared with Suppressed rectangular weir is more efficient than the normal one because square labyrinth weirs give longer lengths for flow to pass over than the normal one where all the percentages of performance more than one.

The study shows that (Cd¬) is greatly affected by the upstream head over the crest (H). It was found that the value of the discharge coefficient(Cd) is high for the low ratios of (H/ P) for all models and gradually decrease with increasing the ratio (H/P), where the model of the square labyrinth weir with semi -circular crest gave the highest value of the discharge coefficient reached (2.55), while the discharge coefficient reached its lowest value reached (0.719) for conventional weir (suppressed rectangular weir) with sharp crest. Also, the shape of crest is one of the most important factor which effects on discharge capacity of labyrinth weirs where the shape of the weir with semi-circular crest gives higher efficiency than the sharp crest shape.

January - February 2020
ISSN: 0193 - 4120 Page No. 1829 - 1838

VI. REFERENCES

[1]. G. Taylor, " The Performance of Labyrinth Weirs", PhD Thesis, University of Nottingham, UK, 1970.

[2]. F. Lux, “Discharge characteristics of labyrinth weirs”, Proc. of Conference on Water for Resources Development, ASCE, Courd’Alene, ID, 1984.

[3]. J. Cassidy., C. Gardner, and R. Peacock, “Boardman labyrinth – crest spillway”, J. Hydraul. Eng., 111(3), 398-416, 1985.

[4]. N. Amanian, and D.Waldron, "Design of labyrinth weir spillways. J. Hydraulic", Eng., ASCE, 121(3), 247–255, 1995.

[5]. B. Noori, And G. Hayawi, "Hydraulic Characteristics of Flow Over Semicircular Sharp-Crested Weirs", Journal of Diraset for Engineering Science, Vol.23, No.1,1996, P.P. 37-46, 1996.

[6]. H. Kocahan, and G. Taylor, "Rehabilitation of Black Rock Dam seepage & inadequate spillway”, Hydroplus, Inc., Arlington, Va, 2002.

[7]. M.E. Emiroglu, N. Kaya, and H. Agaccioglu, "Discharge Capacity of Labyrinth Side Weir Located On a Straight Channel", Journal of Irrigation and Drainage Engineering (ASCE), 136, 37-46, 2010.

[8]. B.M. Crookston, and B. Tullis, “Hydraulic performance of labyrinth weirs”, Proc. of the Int. Junior Researcher and Engineer Workshop on Hydraulic Structures (IJREWHS ’10). Edinburgh, U.K, 2010.

[9]. O. Bilhan, M.E. Emiroglu, and O. Kisi, "Use of Artificial Neural Networks for Prediction of Discharge Coefficient of Triangular Labyrinth Side Weir in Curved Channels", Journal of Advances in Engineering Software, 42, 208-214, 2010.

[10]. R. M. Anderson, and B. P. Tullis, "Comparison of Piano Key and Rectangular Labyrinth Weir Hydraulics", J. Hydraul. Eng. 138:358-361, 2012.

[11]. P. K. Swamee, "Generalized Rectangular Weir Equations", Journal of Hydraulic Engineering, Vol. 114, No. 8, August, ©ASCE, 1988.

[12]. M. G. BOS, "DISCHARGE MEASUREMENT STRUCTURES", THIRD END, INTERNATIONAL INSTITUTE FOR LAND RECLAMATION AND IMPROVEMENT, WAGENINGEN, 1989 .