https://doi.org/10.26682/sjuod.2021.24.2.5
Journal of University of Duhok, Vol. 24, No.2 (Pure and Eng. Sciences), Pp 43-54, 2021

PERFORMANCE IMPROVEMENT OF SHARP CRESTED OBLIQUE WEIRS BY USING VEINS

NAEEMA THAHER AAREF* and BAHZAD MOHAMMAD ALI NOORI**

*Dept. of water Resources Engineering , College of Engineering, University of Duhok, Kurdistan Region-Iraq
** Dept. of Civil Engineering, College of Engineering, University of Duhok, Kurdistan Region- Iraq

(Received: May 25, 2021; Accepted for Publication: August 15, 2021)

ABSTRACT

The current research aims to get better performance and capacity of discharge of sharp crested oblique weirs by providing veins perpendicular to weir crest in order to deflect the water jet perpendicular to the weir axis. Seven weir models have been constructed and experimented in which the weir height and the oblique angle are kept constants as (P = 25cm) and (α = 40º), respectively, during the whole experimental work. Three oblique weir conditions are tested, the first one was testing oblique weir with no veins, while, the second condition was by providing one vein at the middle of crest length and changing vein height three times as (P_v = 25, 20 and 15cm) and the third condition studied was by providing two veins to the oblique weir. From the study of surface profiles, it was realized that the maximum X-distance for the water depth above crest to become horizontal was X = 4.93h from the center of oblique weir with no veins, while, X = 4.59h for oblique weir equipped with one vein and X = 4.93h for oblique weir equipped with two veins (h = upstream water depth above crest). The results of discharge coefficient showed that the ratio of vein height to oblique weir height (P_v/P) has a major role on increasing the discharge coefficient and it was observed that the ratio (P_v/P = 0.6) offers the best performance of the weir. A straightforward power equation is recommended for the relation of (C_d) with (h/P) for sharp crested oblique weir equipped with two veins with high correlation coefficient and low mean percentage error. The capacity of discharge of the oblique weir was increased by 69.6% for a weir equipped with one vein, while, the discharge capacity was increased up to 73.5% for a weir equipped with two veins. The limitations of this study are that testing one oblique angle and keeping the weir height as constant for the range of (h/P) between 0.08 and 0.32.

KEYWORDS: Oblique Weirs, Sharp Crest, Discharge Coefficient, Performance Improvement, Veins.

1. INTRODUCTION

Usually weirs are designed and constructed across open channels or streams to elevate the water level upstream the weir for storage with water flowing over. If the weir separates surface jump clear of thickness, it is called sharp crested (Subramanya, 2009). Moreover, weirs with sharp crests are extensively used as flow measuring devices in laboratories and irrigation projects especially when the flow rate discharge are limited from their resources and the farmers must pay for their water shares (Muhsin and Noori, 2021). In some cases of design, normal sharp crested weirs would not have the capacity of overpassing high flow rate discharges which can be a possible danger and threat to the adjacent private lands. The main practical applications of these types of weirs are that they are used as control structures upstream a dam or across channels to overpass high discharges with low water heads above crest. Using oblique weirs or labyrinth weirs instead of normal weirs considerably reduces the problem of upstream land submergence. A lot of data and information are not accessible for oblique, triangular, and circular planform sharp crested weirs, and there has not been much effort put into enhancing their performance. (Noori and Aaref. 2017).

The present research is being carried out in order to have a better understanding of the hydraulics of flow rates overpassing oblique weirs with sharp crests and trying to improve their performance. Applying veins to the upstream face of the weir is expected to increase the capacity of the weir compared to weirs without veins via manufacturing and constructing different oblique weir models having one vein or two veins with constant

naeema.aaref@uod.ac and bahzad.mohammed@uod.ac

oblique angle. Furthermore, this research aims to formulate the behavior and performance of these types of weirs and finally to recommend useful construction design criteria.

2. REVIEW OF LITERATURE

For the past seventy years, the behavior of flow through sharp crested weirs has piqued the interest of many researchers trying to improve their performance by increasing their capacities through increasing crest length. Giving the crest different shapes such as oblique, triangular, labyrinth and zigzag plan forms will increase the crest length and eventually increase the discharge capacity. Aichel (1953) published one of the early studies on the behavior of oblique sharp crested weirs, in which he measured the discharge ratio of an oblique weir to a regular weir at various oblique angles. To examine the influence of oblique weir angle, De Vries (1959) published a report to study the influence of oblique weir angle on the discharges passing over sharp crested oblique weirs.

According to Chilmeran (1996) and Noori and Chilmeran (2005), the coefficient of discharge of oblique weirs with semi-circular crests falls as the head to crest height ratio increases, and weirs with a small oblique angle have smaller coefficient of discharge values but passing higher discharges. They also showed that, for both normal and oblique weirs, rounding the crest as a semicircle enhances discharge magnification. A wide range of oblique angle are tested by Borghei et al. (2006) and their laboratory results are presented as charts for the relation of coefficient of discharge with relative head over crest presenting a general equation for the discharge coefficient in terms of channel width, length of weir, height of weir and head over weir crest. A theoretical approach has been presented by Kabiri – Samani (2010) to investigate the properties of both weir and flow on the coefficient of discharge of sharp crested oblique weirs.

Kumar et al. (2011) and Kumar et al. (2013) conducted two separate studies; the first one was to improve the discharge magnification of triangular plan form weirs and the other was empirical study to analyze the free flow over sharp crested plan form weirs for a wide range of vertex angles between 0 and 120 degrees, while, keeping the weir height constant for the whole experimental work. Gupta et al. (2013) and Gupta et al (2015) presented two separate laboratory studies, the first one was to investigate the behavior of free flow over contracted weirs testing a wide range of vertex angles, while keeping the height of weir constant. While, in the second study, the effect of weir height was studied showing that discharge coefficient and discharge capacity increase with the decrease of weir height.

An intensive study on the hydraulics of flow over triangle plan form sharp crested has been conducted by Noori and Aaref (2016) through testing different weir models concluding that discharge coefficient decreases with the increase of relative upstream water depth above crest presenting an empirical equation for the coefficient of discharge and they showed that small vertex angle weirs give higher magnification values and higher efficiency. Another study is presented by Noori and Aaref (2017) focusing on the performance improvement of triangular plan form weirs by circulating their weir crests through testing twenty-seven weir models in which the vertex angle, weir height and crest diameter are changed during the experimental work. Noori and Aaref (2017) showed that the discharge capacity can be increased by 138% compared to normal sharp crested weirs in case of weirs of vertex angle of 45 degrees, weir height of 15 cm and crest diameter of 2.54 cm, i.e., the ratio of crest diameter to weir height = 0.17.

A recent laboratory work on the performance improvement of oblique weirs has been done by Noori (2020) via testing twenty-four oblique weir models having circular crests in which different values of oblique angle, weir height and crest diameter are tested. Noori (2020) presented a simple method for the design of circular crested oblique weirs and showed that the discharge capacity can be increased up to 175% compared to normal sharp crested weirs for weirs of oblique angle of 20 degrees, weir height of 20 cm and crest diameter of 4 cm (ratio of crest diameter to weir height = 0.2) through circulating weir crest.

In the present research, the writers aim to improve the discharge capacity and performance of sharp crested oblique weirs by providing veins perpendicular to the upstream face of the weir in order to deflect the overpassing flow jet perpendicular to the weir axis and finally increasing the overtopping flow rate and enhancing weir performance.

naeema.aaref@uod.ac and bahzad.mohammed@uod.ac

3. EXPERIMENTAL WORK AND INSTRUMENTATION

The empirical work of the present research was conducted at the laboratory of hydraulics of Water Resources Engineering Department of Duhok University. Seven models of oblique weir are made and tested with constant crest height (P = 25cm) and constant oblique angle ($\alpha = 40^o$) in a straight steel incline flume with working length of 5 m and constant cross section 0.3 m wide and 0.45 m deep. Three weir models are made from Perspex sheets of 2mm thickness with one vein fixed at the middle of crest length of dimensions 6 cm width and variable heights. The height of the vein is changed three times as (h_v = 25, 20 and 15cm) while keeping the vein width constant. To study the impact of multi-veins, three oblique weir models are equipped with two veins in which the vein width is kept constant, while the height is changed three times as mention in the first condition tested. One oblique weir model is constructed and tested free of veins just for the purpose of comparison of results. In Table (1), all details of the weir models tested during the experimental work of the present search are shown. A typical drawing of an oblique weir model equipped with two veins is displayed in the Fig. (1).

Table (1):- Details of the oblique weir models tested during the experimental work

Model No.	Height of weir P (cm)	No. of Veins	Height of veins P_V(cm)	Oblique angle α (degree)	Crest length L_c (cm)	Shape of crest	No. of runs
1	25	1	25	40^o	46.67	Sharp	**7**
2	25	1	20	40^o	46.67	Sharp	**7**
3	25	1	15	40^o	46.67	Sharp	**7**
4	25	2	25	40^o	46.67	Sharp	**7**
5	25	2	20	40^o	46.67	Sharp	**7**
6	25	2	15	40^o	46.67	Sharp	**7**
7	25	Non	-	40^o	46.67	Sharp	**7**
						Total=49	

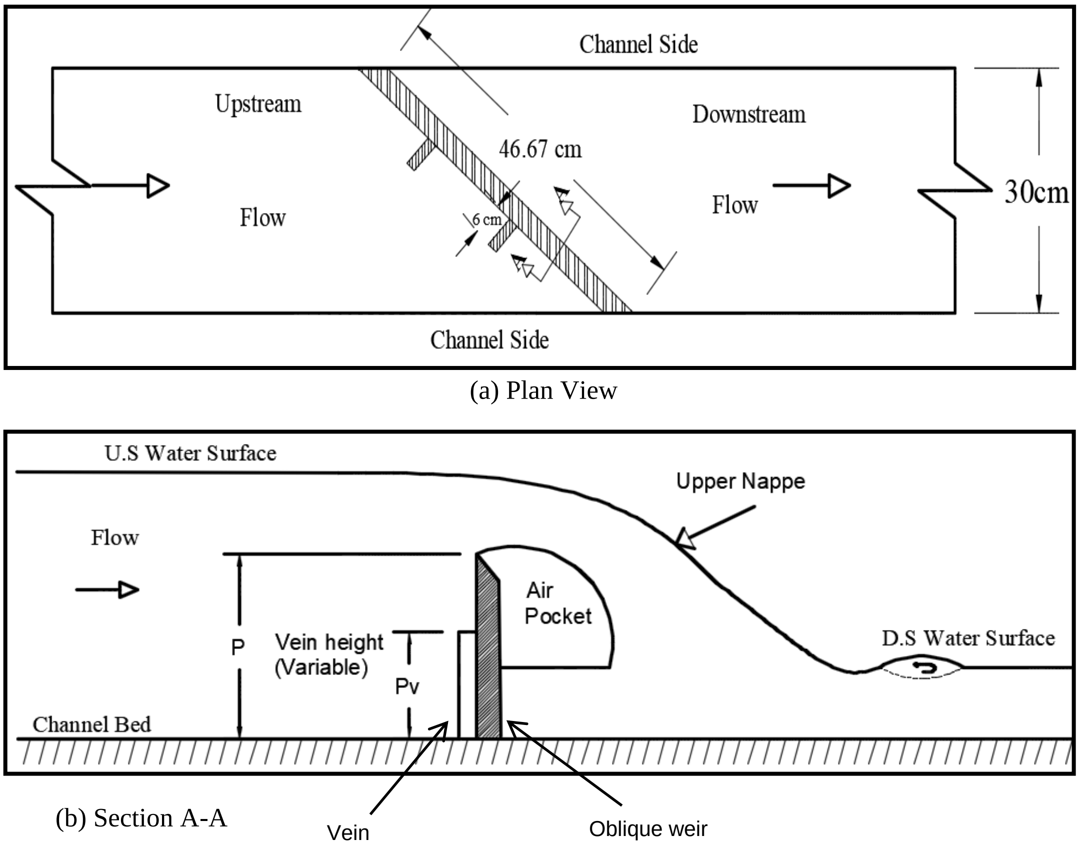

Fig. (1): Plan and section of a typical sketch of the oblique weir model

naeema.aaref@uod.ac and bahzad.mohammed@uod.ac

The testing work started by fixing every weir model at a distance 3 m downstream the flume inlet. The model was fixed at the center of pure glass panel to keep it away from inflow disruption and to visualize the testing process. All gabs are filled with a silicon glue to avoid any water leakage through the weir model, flume sides and bed. Flow rates are allowed to overpass the weir model through a delivery pipe from a centrifugal pump of maximum discharge capacity of 40 l/s starting with low flow rates. The flow rate was gradually increased taking about seven test runs on each weir model. Water surface profile measurements are taken during each experiment while measuring water depths along the flume's centerline for 2 cm intervals. A total of 49 experiments are carried out for the current research work (see Table (1)). Fig. 2 shows photographs of the oblique weir models 2 and 5 during test runs with one and two veins, respectively

(a) Weir model 2 (b) Weir model 5

Fig. (2): Photographs of oblique sharp crested weir models 2 and 5 during test runs respectively

4. RESULTS AND DISCUSSION

(a) Surface Profiles of Water

All data of surface profiles of water are taken over the middle of the flume for every weir model starting from the weir crest toward upstream and downstream the weir crest for small intervals of 2 cm in order to plot the surface profile for each test run on the oblique weir model. The advantage of water surface profiles involves in determining the nearest location of uniform water depth above crest away from the crest of the weir. As a sample, Fig. (3) shows the dimensionless surface profiles of water along the centerline of the flume for the sixth oblique weir model tested in the present study with constant weir model height (P = 25 cm) and constant oblique angle (α = 40°) equipped with two veins by plotting the relation of (Y/h) against (X/h), where Y is water depth above crest at any distance (X) and X is the upstream distance along the flume centerline measured from the upstream face of the weir model. Water surface profiles calculations of the above case illustrated in Fig. (3) are shown in Table (2). The general feature of surface profile shows a gradually rising trend starting from the weir crest towards upstream channel, while, the water surface profile downstream crest showed a sudden drop near the downstream face of the crest. A summary of the surface profile results is shown in Table (3). Table (3) depicts that the maximum X-distance for the water surface to become horizontal and uniform is X = 4.93h for oblique weir model with no veins. The distance X is ranging between 3.65h and 4.59h for oblique weir model equipped with one vein and the smaller range is recorded for the smaller height of vein (P_v =15 cm). Moreover, the X-distance is ranging between 3.53h and 4.93h for oblique weir models equipped with two veins and the smaller range is recorded for the longer height of veins (P_v = 25 cm). As a final conclusion from the above discussion, the existence of veins reduces the relative X-distance upstream the oblique weir model.

naeema.aaref@uod.ac and bahzad.mohammed@uod.ac

Table (2): Water surface profile results for the sixth weir model with two veins(P =25cm,Pv =15cm and α = 40º)

Q (l/s)	h (cm)	h/P	X (max) cm	Y/h	X/h
2.89	2.05	0.082	2.6	1	1.248
4.99	3.05	0.122	4.5	1	1.498
7.051	4.05	0.162	7.0	1	1.747
10.09	5.05	0.202	11.9	1	2.372
12.82	6.01	0.240	21.8	1	3.620
16.15	7.05	0.282	29.8	1	4.245
19.29	8.01	0.32	38.4	1	4.868

Table (3):- A summary of water surface profile analysis results

Weir condition	Weir height (cm)	Oblique angle	Height of vein (cm)	Y/h	X/h
Without veins	25	40º	Zero	1	4.93
With one vein	25	40º	25	1	4.59
With one vein	25	40º	20	1	4
With one vein	25	40º	15	1	3.65
With Two veins	25	40º	25	1	3.53
With Two veins	25	40º	20	1	4.93
With Two veins	25	40º	15	1	4.87

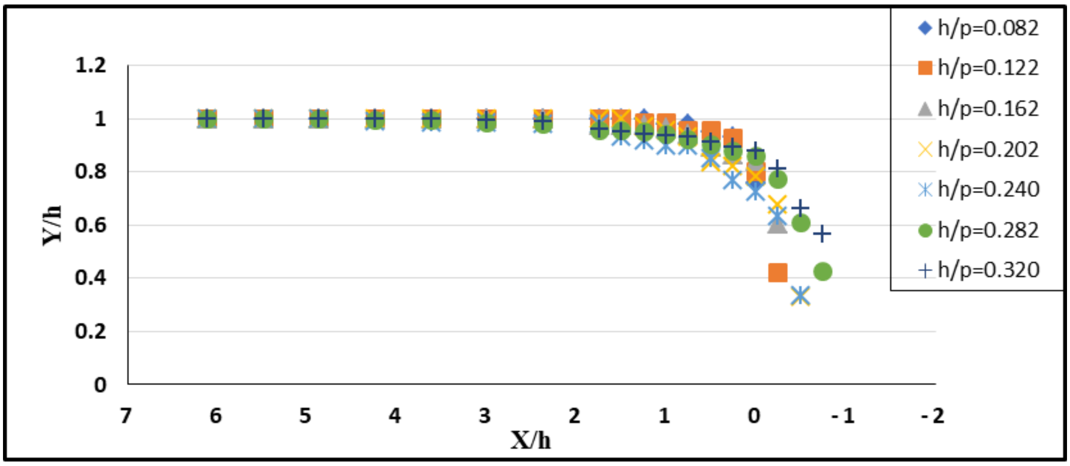

Fig. (3): Relation of Y/h with X/h along the centerline for all test runs on sixth weir model with two veins (P = 25cm, P_v = 15cm and α = 40º)

(b) Discharge Coefficient

The discharge passing over the oblique weir (Q_{ob}) can be estimated using the general equation of sharp crested oblique weirs as (Noori, 2020):

$$Q_{ob} = \frac{2}{3}\sqrt{2g}\ C_d\ L_c\ h^{\frac{3}{2}} \qquad (1)$$

in which, C_d = coefficient of discharge, L_c = length of crest of oblique weir, h = upstream water depth above crest and g = acceleration due to gravity.

For each test run, the discharge overpassing oblique weir is recorded and the upstream water depth above crest is measured at a location where it becomes horizontal and the crest length of oblique weir (L_c) is calculated as:

$$L_c = \frac{W}{\sin(\alpha)} \qquad (2)$$

in which, W = flume width and α = oblique angle kept constant as α = 40º, therefore, L_c= 0.4667m.

naeema.aaref@uod.ac and bahzad.mohammed@uod.ac

The relationship of coefficient of discharge (C_d) with the relative depth above crest (h/P) is studied for constant weir height (P = 25 cm) and constant oblique angle (α = 40°) but different number of veins equipped to the oblique weir and with different vein heights. Fig (4) shows the relations of (C_d) with (h/P) for constant vein height (P_v = 25cm) and the weir is equipped with one vein, two veins and none demonstrating clearly that oblique weir with two veins overpasses higher discharges compared to the weir with one vein or none. Similar sets of curves are plotted for vein heights (P_v) = 20 cm and 15 cm in Figs. (5) and (6), respectively. From Figs (5) and (6), even though the vein heights are lesser, an oblique weir equipped with two veins overpasses a higher discharge. The variation of (C_d) with (h/P) for an oblique weir with two veins but differing vein heights is intriguing to investigate, see Fig (7). It is quite clear that oblique weir provided with two veins of height (P_v) = 15 cm offers higher values of (C_d) demonstrating that this height of vein passes higher discharge over the oblique weir. This hydraulic behavior of veins can be attributed to the reason that the ratio of vein height to oblique weir height (P_v/P = 0.6) will well deflect the flow jet stream lines perpendicular to the crest axis compared with other vein heights. The general simple power expression for the relation of (C_d) with (h/P) for the performance of oblique weirs for different conditions tested in this study is:

$$C_d = c_1 \left(\frac{h}{p}\right)^{c_2} \quad (3)$$

where, Table (4) shows the values of c_1 and c_2 as well as the corresponding values of the correlation coefficient (R) demonstrating high correlation coefficient values.

Table (4): Values of constants (c_1), (c_2) and correlation coefficient (R) of Eq. (3) for different number of veins and different heights

Vein height (Pv) = 15 cm								
One vein			Two veins			Without veins		
c_1	c_2	R	c_1	c_2	R	c_1	c_2	R
0.4562	-0.163	0.985	0.5458	-0.107	0.999	0.468	-0.134	0.972
Vein height (Pv) = 20 cm								
One vein			Two veins			Without veins		
c_1	c_2	R	c_1	c_2	R	c_1	c_2	R
0.4234	-0.188	0.981	0.4636	-0.159	0.979	0.4355	-0.157	0.984
Vein height (Pv) = 25 cm								
One vein			Two veins			Without veins		
c_1	c_2	R	c_1	c_2	R	c_1	c_2	R
0.337	-0.254	0.963	0.4448	-0.162	0.996	0.3602	-0.237	0.968

From the forgoing debate, it is quite clear that the oblique weir having constant weir height and constant oblique angle equipped with two veins of relative vein height (P_v/P = 0.6) is performing much better than other weirs and its equation of discharge coefficient is:

$$C_d = \frac{0.5458}{\left(\frac{h}{p}\right)^{0.107}} \quad (4)$$

Eq. (4) is obtained with a correlation coefficient (R = 0.999) and the range of (h/P) between 0.082 and 0.320.

Variation of the predicated values of (C_d) (Obtained from Eq. (4)) with those observed experimentally is shown in Fig. (8) showing the line of perfect agreement.

The validation of Eq. (4) can be checked via using the following equation (Noori, 2020) as:

$$MPE\ \% = \frac{100}{N} \sum \left[\frac{Cdp - Cdo}{Cdo}\right] \quad (5)$$

in which, MPE = mean percentage error, C_{dp}= predicted values of (C_d), (C_{do}) = experimentally observed values and N = number of test runs. The percentage error in computation of discharge coefficient is found to be 0 to ± 0.62% for oblique weir model of weir height (P) = 25cm equipped with two veins of height (P) = 15 and for the range of (h/P) between 0.082 and 0.320.

naeema.aaref@uod.ac and bahzad.mohammed@uod.ac

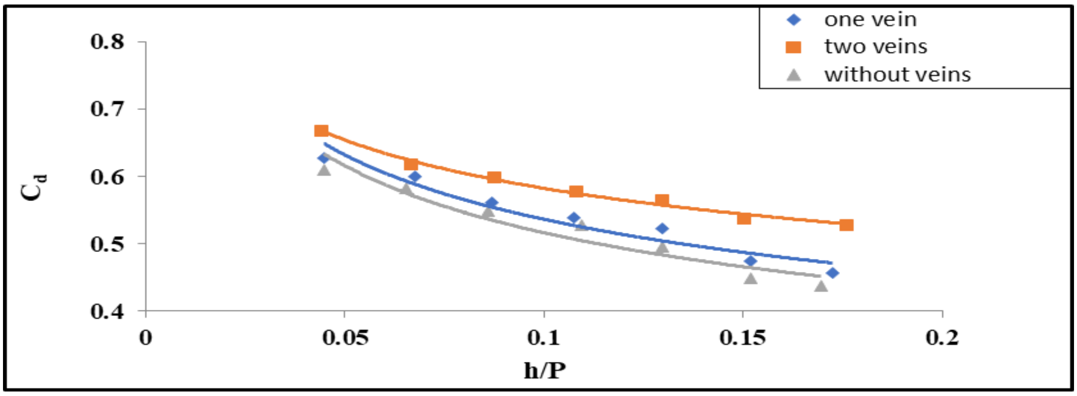

Fig. (4): Variation of (C_d) with (h/P) for vein height (P_v = 25 cm) and different cases of vein

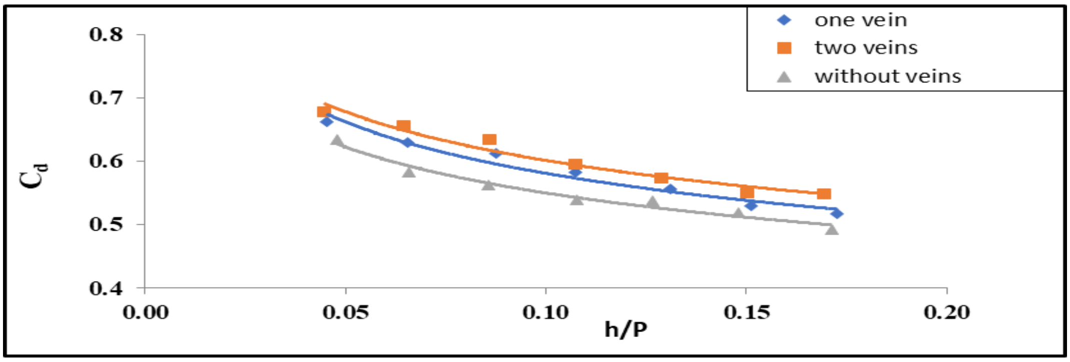

Fig. (5): Variation of (C_d) with (h/P) for vein height (P_v= 20 cm) and different cases of veins

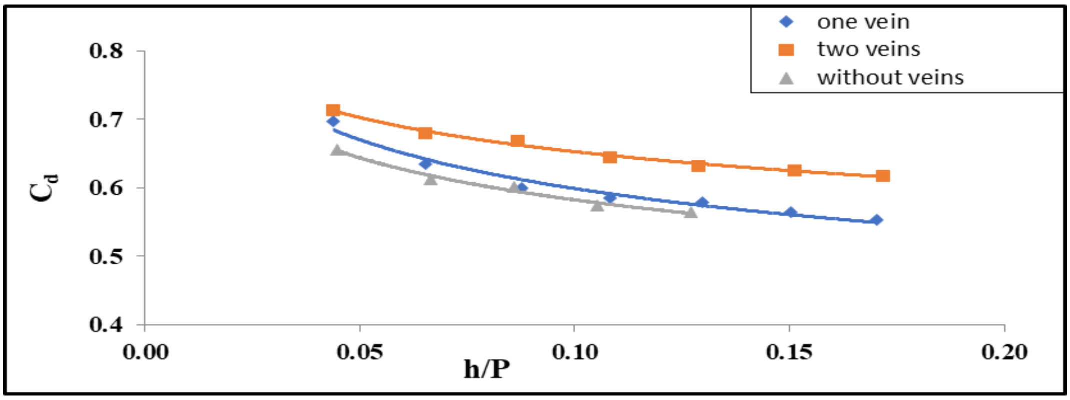

Fig. (6): Variation of (C_d) with (h/P) for vein height (P_v= 15 cm) and different cases of vein

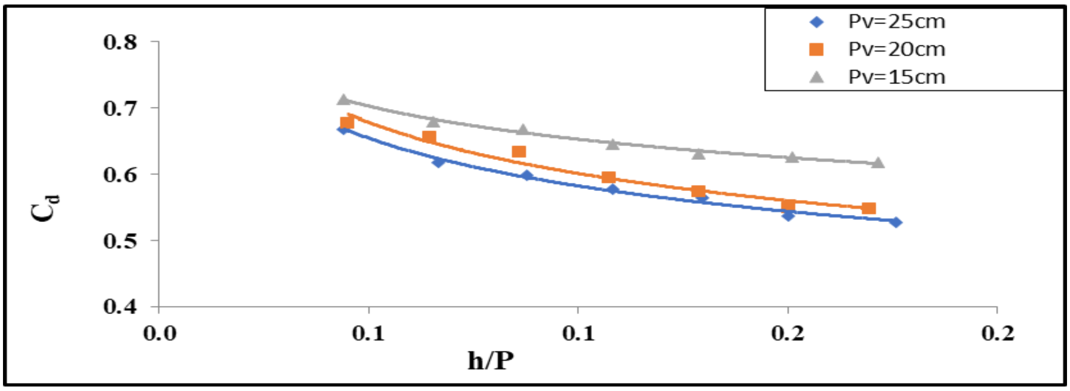

Fig. (7): Variation of (C_d) with (h/P) for oblique weir equipped with two veins of different heights

naeema.aaref@uod.ac and bahzad.mohammed@uod.ac

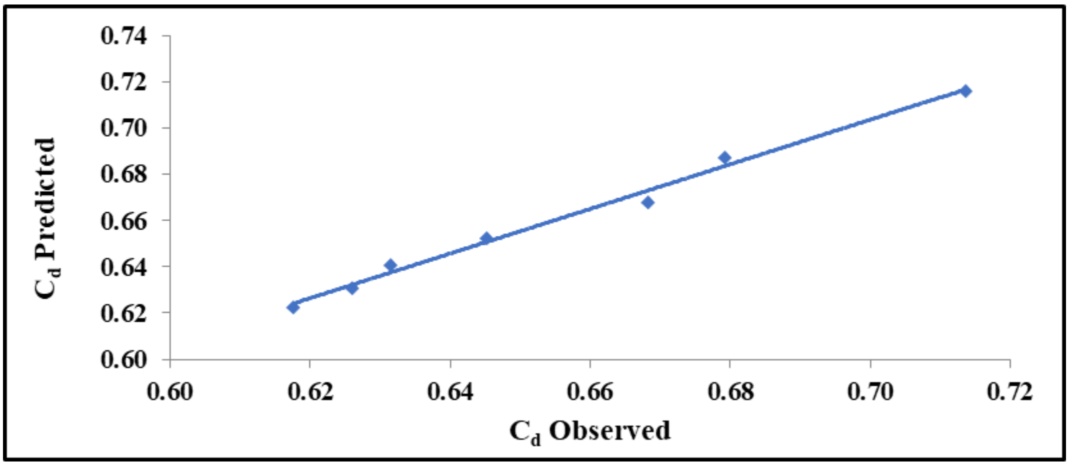

Fig. (8): Predicted values of (C_d) versus practical ones for P = 25cm, (P_v) =15cm and (P_v/P) = 0.6

(c) Weir efficiency

The effectiveness of oblique weirs with veins is investigated by comparing the flow overpassing the oblique weir (Q_{ob}) with the flow overpassing a conventional sharp crested weir (Q_{ns}), both of which occupy the same flume width and have the same upstream water depth above the crest. The discharge (Q_{ns}) can be accurately calculated using the British Standard Institute's well-known equation (British Standard,1995):

$$Q_{ns} = \frac{2}{3}\sqrt{2g}\left(0.602 + 0.083\frac{h}{p}\right) * W * (h + 0.0012)^{\frac{3}{2}} \qquad (6)$$

where, W = crest length of normal sharp crested weir (flume width), h = upstream water depth above crest and P = weir height above flume bed (0.25 m).

Weir efficiency (weir discharge magnification) is expressed as the ratio (Q_{ob}/Q_{ns}). The discharge efficiency (or discharge magnification) is plotted against (h/P) in Figs (9, 10, 11, and 12) for constant weir height (P = 25cm), different values of vein height of one vein, two veins and without veins.

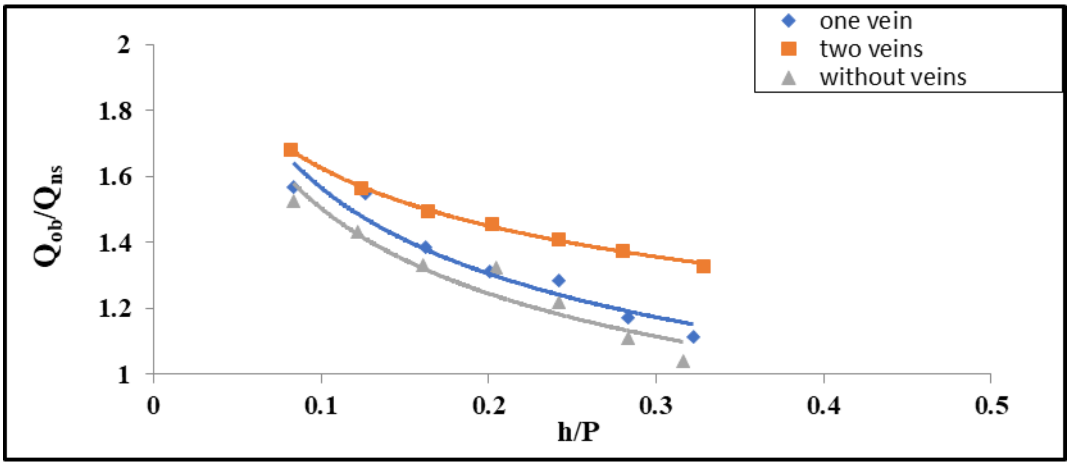

Fig. (9): Variation of (Q_{ob} /Q_{ns}) with (h/P) for vein height (P_v) = 25cm

naeema.aaref@uod.ac and bahzad.mohammed@uod.ac

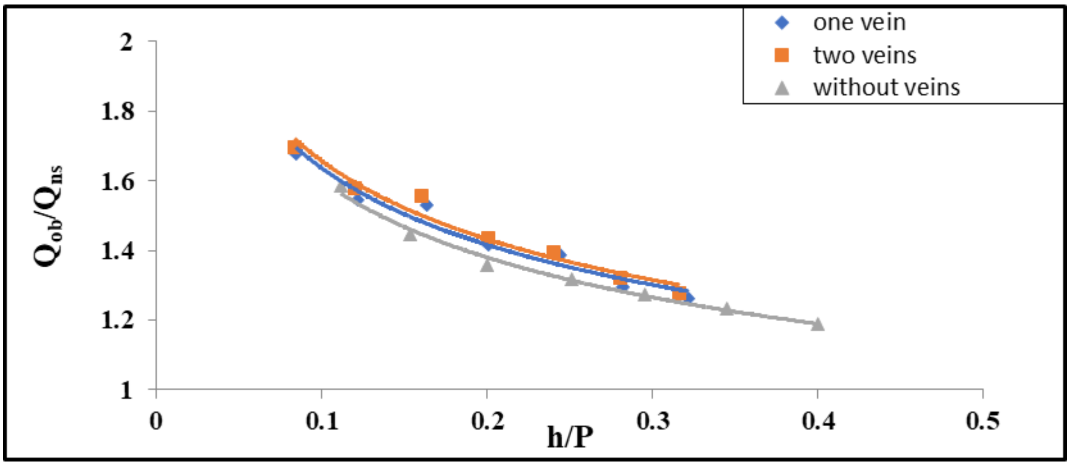

Fig. (10): Variation of (Q_{ob} /Q_{ns}) with (h/P) for vein height (P_v) = 20cm

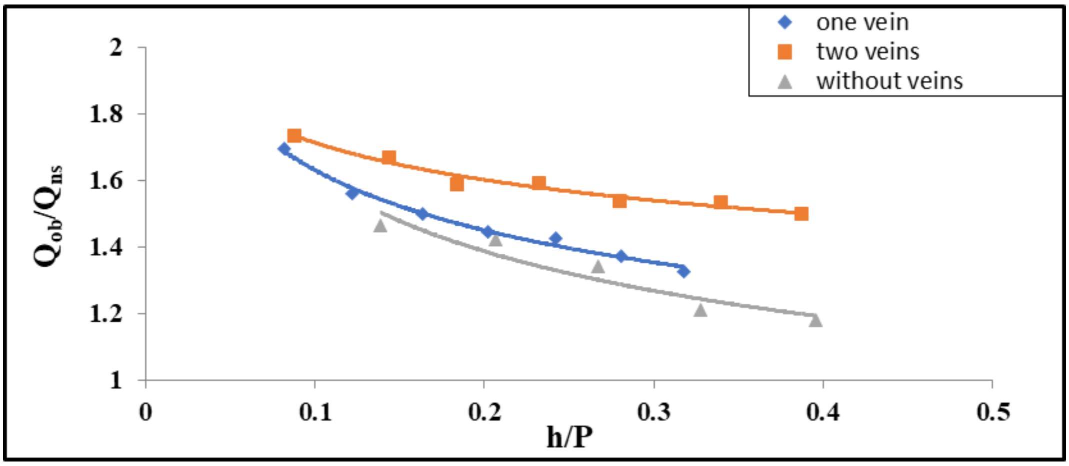

Fig. (11): Variation of (Q_{ob} /Q_{ns}) with (h/P) for vein height (P_v) = 15cm

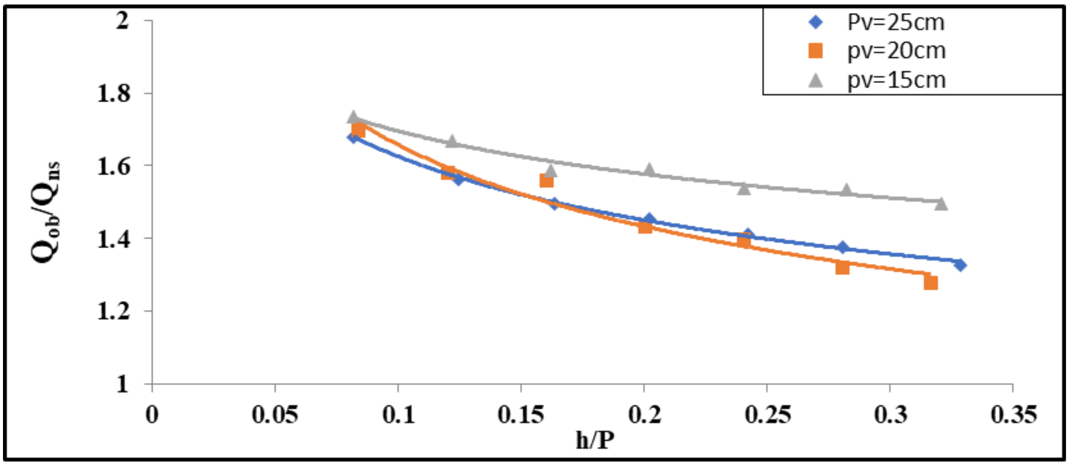

Fig. (12): Variation of (Q_{ob} /Q_{ns}) with (h/P) for two veins of different heights

From Figs (9 to 12), one may realize the following outcomes:

1- The weir efficiency falls as the (h/P) value increases, which can be attributed to the fact that for small (h/P) values, the behavior is practically ideal along the entire crest length, resulting in high discharge efficiency. This behavior is explained by the fact that for small values of

naeema.aaref@uod.ac and bahzad.mohammed@uod.ac

(h/P), the flow rate is low and the velocity head of flow is negligibly tiny and variations in the water depth because of contraction are negligibly tiny. Consequently, depth of water is the same overall crest length and so on the flow rate per crest length is the same.

2- For constant oblique weir height and different values of vein height, oblique weir equipped with two veins offers the highest efficiency of the weir (highest discharge magnification) compared with weirs equipped with one vein or without veins through giving the highest values of (Q_{ob} /Q_{ns}), see Figs. 9 to 11.

3- From Fig. (12), one may clearly realize that the oblique weir equipped with two veins of vein height (P = 15 cm) offers the highest value of weir efficiency (maximum discharge magnification). This behavior may be credited to the reason that two veins of height ratio (P_v/P) = 0.6 perform very well in deflecting the jet streamlines perpendicular to the crest axis and consequently increasing the overpassing discharges.

Table 1 shows the least and greatest percentages increase in discharge overtopping sharp crested oblique weirs of various vein heights and with one, two, or no veins compared to discharges overtopping sharp crested normal weirs of the same weir height and occupying the same flume width are illustrated in Table (4). This table shows that the oblique weir with oblique angle (α) = 40^o and height of weir (P) = 25cm increases the percentage of discharge between 3.9% and 58.6% with no veins, while, applying the oblique weir with one vein of height (P_v) = 15cm increases the percentage of discharge by 32.6% to 69.6% and if the oblique weir is equipped with two veins of height (P_v) = 15cm, the weir offers the highest values of percentage increase in discharge ranging between 49.7% and 73.5% giving this weir model an important role in design.

Table (4): Least and greatest percentages increase of discharge for different weir conditions and different vein heights

Weir condition	% increase of discharge for different vein heights					
	Vein height (P_v=15cm)		Vein height (P_v=20cm)		Vein height (P_v=25cm)	
	Min.	Max.	Min.	Max.	Min.	Max.
No vein	18	46.5	19	58.6	3.9	52.5
One vein	32.6	69.6	26.2	67.9	11.4	56.9
Two veins	49.7	73.5	27.8	69.6	32.8	67.9

(d) Comparing the results of this research with those of circular crested oblique weirs

To check the validity of the present study results, it is interesting to compare them with those of circular crested oblique weirs presented by Noori (2020). The experimental results of this study for the stage discharge relationship of sharp crested weir equipped with two veins of ratio of vein height to weir height (P_v /P) = 0.6 shown in Fig. (13) are compared with the experimental results of circular crested oblique weir results of oblique angle of 40 degrees, weir height of 30 cm and crest diameter of 5.1 cm. From Fig. (13), one may clearly realize that the results of the present study compare quite well with those of Noori (2020) which means that the discharge capacity and performance of sharp crested weirs equipped with veins of ratio (P_v/P) are very close to those of circular crested oblique weirs. Moreover, the advantages of sharp crested oblique weirs equipped with veins over other types of weirs that they are simple and economic in design and construction compared with other types of weirs such as circular crested oblique weirs.

naeema.aaref@uod.ac and bahzad.mohammed@uod.ac

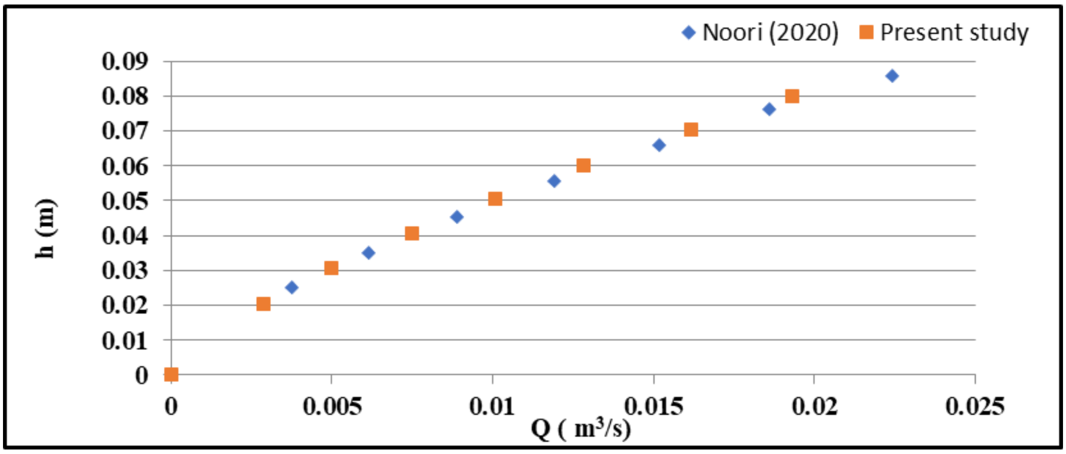

Fig. (13): Comparison of present research results with those of circular crested oblique weir

5. SUMMARY AND CONCLUSIONS

The objective of this research is to enhance the performance of sharp crested oblique weirs via providing the weir with veins. As a result, the capacity of discharge and weir efficiency is increased and the actual behavior and hydraulics of these types of models are better studied and formulated. The experimental work included testing seven models of oblique weir in which the oblique angle and weir height are kept constant as $\alpha = 40^o$ and P = 25cm, respectively. Three main weir conditions are studied, the first one was testing oblique weir with no veins, while, the second condition was by providing one vein at the middle of crest length and changing the vein height three times and the third condition was by providing the oblique weir with two veins and changing the vein height three times. The main fruitful outcome conclusions of the present research can be summarized as:

From the result of surface profiles of water, it is observed that the maximum X-distance for the water depth above crest to become horizontal and uniform is X = 4.93h for oblique weirs without veins. The distance X is ranging between 3.65h and 4.59h for oblique weir equipped with one vein and X- distance is ranging between 3.53h and 4.93h for oblique weir equipped with two veins.

The impact of vein height on the discharge coefficient is studied intensively in the present research in order to get the best ratio of vein height to oblique weir height (P_v/P) impacting the discharge coefficient and eventually passing the highest discharge capacity. It is clearly observed that the ratio (P_v/P = 0.6) offers the best performance of the weir which deflects the jet flow lines perpendicular to the crest axis resulting higher discharge capacity passing over the oblique weir. A power expression is recommended for the relation of (C_d) with the relative depth above crest (h/P) for sharp crested oblique weir equipped with two veins and the validation of this equation is checked via finding the mean percentage error (MPE) = 0 to ±0.62 % for the best performed oblique weir studied in the present research.

1- The efficiency of the oblique weirs tested in the present research showed that the capacity of discharge of oblique weir with sharp crest is increased by the range between 3.9% to 58.6% for no veins provided to the oblique weir, while, applying one vein to the oblique weir the discharge capacity is increased by 32.6% to 69.6% and finally when the oblique weir is equipped with two veins the discharge capacity range is increased by 49.7% to 73.5% giving this weir condition to be the most favorable among others for the design purpose of these types of weirs.

REFERENCES

Aiched, O.A. (1953),″ Discharge Ratios for Oblique Weirs″, Z.VDI, 95 (1); PP. 26-27.

Borghei, S.M. Kabiri – Samani, A.R. and Nekoee, N. (2006), ″Oblique Weir Equation Using Incomplete Self-Similarity″, Canadian Journal of Civil Engineering, CJCE, 33 (10); PP, 1241 – 1250.

British Standard Institution (1965), "Methods of Measurement of Liquid Flow in Open Channels″, London, England, B53680, Part 4A.

Chilmeran T.A.H. (1996), "Characteristics of Flow over Normal and Oblique Weirs with Semi-Circular Crests″, M.sc thesis, Dept. of

naeema.aaref@uod.ac and bahzad.mohammed@uod.ac

Irrigation and Drainage Engineering, University of Mosul, Mosul, Iraq.

De Vries, M. (1959), ″Oblique Weirs‟, Report WL, Delft, Hydraulics Laboratory, Netherlands, In Dutch.

Gupta, K.K., Kumar S. and Kumar K. (2013) ‟Flow Characteristics of Sharp –Crested Triangular Contracted Weirs‟, International Journal of Engineering Research and Technology (IJERT), 2 (12); PP. 1252-1258.

Gupta, K.K., Kumar, S. and Ahmad, Z. (2015), ‟Effect of Weir Height on Flow Performance of Sharp Crested Rectangular-Plan Form Weir‟, World Applied Sciences Journal, 33 (1); PP. 168 – 175.

Kabiri –Samani, A.R (2010), ‟Analytical Approach for Flow over an Oblique Weir‟, Transaction A, Civil Engineering, PP. 107–117.

Kumar, S, Ahmad Z. and Mansoor, T. (2011), ‟A new Approach to Improve the Discharging Capacity of Sharp Crested Triangular Plan Form Weirs‟, Journal of Flow Measurement Instrumentation, Elsevier, 22; PP. 175-180.

Kumar, S. Ahamd Z. Mansoor, T. and Himanshu, S.K. (2013), ‟A New Approach to Analyze the Flow over Sharp-Crested Curved Plan Form Weirs‟, International Journal of Recent Technology and Engineering, 2 (1); PP. 24-28.

Muhsin K.A. and Noori, B.M.A (2021), ‟ Hydraulics of Free Over fall in Smooth Triangular Channels‟, Ain Shams Engineering Journal, Elsevier, Article in Press, Available Online. March, 7.

Noori, B.M.A and Chilmeran, T.A.H (2005), ‟Characteristics of Flow over Normal and Oblique Weirs with Semicircular Crests", Al-Rafidain Engineering Journal: 13 (1); PP. 49 – 61.

Noori, B.M.A and Aaref, N.T (2016) ‟Hydraulic Behavior of Sharp Crested Triangular Plan Form Weirs‟, Journal of Duhok University (Pure Engineering and Science), 19 (1); PP. 331-341.

Noori, B.MA and Aaref, N.T (2017), ‟Hydraulic Performance of Circular Crested Triangular Plan Form Weirs‟, Arabic Journal for Science and Engineering 42 (9); PP. 4023 – 4032.

Noori, B.MA. (2020), ‟Hydraulic Performance of Circular Crested Oblique Weirs‟, Ain Shame Engineering Journal Elsevier, 11(4); PP. 875 – 888.

Subramanya, K. (2009), ‟Flow in Open Channels‟, 3rd Edition, Tata Mc Graw Hill Education Private Limited, New Delhi.

Tingey, S.E. (2011), ‟Discharge Coefficients of Oblique Weirs‟, M.Sc. Thesis, Dept. of Mechanical Engineering, Utah State University, Logan, Utah, U.S.A.

naeema.aaref@uod.ac and bahzad.mohammed@uod.ac