Journal of Babylon University/Engineering Sciences/ No.(2)/ Vol.(23): 2015

Removal Efficiency of Sediment by Self-Cleaning of Combined Rectangular Weir with Three Ectangular Bottom Openings by Using ANN

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Abstract

This research was based on laboratory experiments for obtaining the sediment removal efficiency for a rectangular weir with three rectangular bottom openings. Thirty-three physical models were made for weir without openings, weir with one opening, weir with three openings, for purpose of comparison. These models were operated under clear-water condition and by using the uniform cohesion less sand as bed material. Dimensional analysis was made to relate the maximum scour depth, width and length of the scour holes created at the upstream and downstream sides of the weir, with different geometrical and flow variables for each flow case. The *SMS Software-RMA2 Model* was used to obtain the velocity distribution to be related to the simulation of the self-cleaning efficiency for the proposed weir models. The coefficients of variation for the estimated removal efficiency of sediments at both sides were (1.113 -0.465), which indicate the necessity of obtaining a model to describe this variation. Experimental data analysis had shown the flow conditions such as the head difference ,the head over the weir, time, dimensions of openings, number of openings have considerable effect on the scour holes volume at both sides of the weir. ANN models were developed herein using the (*SPSS software*, version 19) to express the removal efficiencies of sediment both at the upstream and downstream sides of the weir as a function of the different geometrical and flow variables. These obtained ANN models were found to have correlation coefficients range (r=0.989 - 0.803) between the observed and predicted removal efficiencies. These high correlations indicate the capability of these models for a very good predictions. These models were used in a *Visual Stuido Net,2010*program in order to be used by engineers to find the removal efficiency of such structure.

Key word: Removal Efficiency, Sediment, Self-Cleaning, Combined Rectangular

الخلاصة:

تم في هذا البحث اعتماد التجارب المختبرية لدراسة النحر الحاصل في مقدم ومؤخرالهدارالمستطيل ذو ثلاث فتحات مستطيلة الشكل في اسفله،(متساوية الابعاد). تم عمل (٣٣) نموذج مختلف من هذا المنشأ بأختلاف الابعاد لكل من الهداروالفتحات لثلاث حالات مختلفة (للهدار بدون الفتحات السفلية وللهدار بفتحة واحدة وللهدار بثلاث فتحات) لاغراض المقارنة.

وضعت هذه النماذج في القناة المختبرية تحت ظروف الجريان الهادئ (*subcritical*) والخالي من حمل الرسوبيات (*clear water-condition*)، وبأستخدام تربة رملية ذات جزيئات منتظمة وغير متماسكة كمادة للقاع.

تم اجراء تحليل بعدي لأيجاد علاقة لا بعدية بين(اعلى قيمة لعمق وطول وعرض حفرة النحر عند مقدم ومؤخر الهدار) و متغيرات تمثل ابعاد النموذج و أخرى تمثل الجريان لكل حالة جريان. وتم دراسة نمط توزيع السرع بأستخدام برنامج (*RMA2*) لتمثيل محاكاة التنظيف الذاتي لنماذج النحر. كما ان قيم معامل التغيير لكل حالات الجريان في تخمين كفاءة الازالة لكلا الجانبين من الهدار كانت (0.465- 1.113) مما يشير الى ضرورة الحصول على نموذج لوصف هذا التغيير. من تحليل النتائج المختبرية تبين ان فرق الارتفاع، منسوب المياه اعلى الهدار،الوقت، عدد وحجم الفتحات ،من العوامل المؤثرة في حجم حفرة النحر في كلا الجانبين من الهدار.

يقوم نموذج (*ANN*) بأيجاد كفاءة الازالة للرسوبيات في مقدم ومؤخر الهدار كدالة لمختلف المتغيرات المتعلقة بالابعاد الهندسية الخاصة بالنموذج والمتغيرات التي تمثل الجريان بقيم معامل ارتباط لكل الشبكات يتراوح بين (r=0.989-0.803) لكفاءة الازالة المحسوبة والمقاسة .تشيرالقيم العالية للارتباط الى امكانية التنبؤ العالي للموديل كما تم بناء نموذج (*Visual* Studio Net,2010) لغرض استخدامه من قبل المهندسين لأيجاد كفاءة الازالة للرسوبيات لجميع النماذج.

الكلمات المفتاحية: كفاءة الإزالة، والرواسب، والتنظيف الذاتي، جنبا إلى جنب مستطيلة

1. Introduction

Weirs and gates are the common and important structures which are used in controlling and adjusting the flow in irrigation channels. Weirs widely used for flow measurements. One of the weirs demerits is the continuous needs of removing the accumulated sediments near the structure. Sluice gates had been used extensively for flow control and water measurement since long time. One disadvantage of the sluice gates is they retained the floating materials. In order to maximize their advantages, weirs and gates can be combined together in one device, so that water could pass over the weir and below the gate simultaneously. The combined weir and gate systems can be used in minimizing sedimentation and deposition.

Several research works can be found in the literature for the combined weir overflow and the gate underflow, simultaneously. The first idea of simultaneous flow over the weir and under the gate was introduced by Majcherek (1984).Negm (1995, 1996) analyzed the characteristics of the combined flow over contracted weirs and below contracted gates of rectangular shape with unequal contractions. Ferro (2000) reported the results of an investigation carried out to establish the stage discharge relationship for a flow simultaneously discharging over a weir and under a sluice gate. Problems concerning sedimentation and depositions are minimized by combined weirs and gates as outlined by Alhamid *et al*. (1997).Fadil (1997) developed a meter for the combined flow through contracted sluice gate and weir. Combined-submerged flow through weirs and below gates were analyzed and discussed by Negm(2000). Negm *et al*.(2002) conducted some experiments to study the characteristics of the combined flow over the sharp-edged rectangular weir and below the sharp-edged rectangular gate with contractions. He introduced a general dimensionless relationship for predicting the discharge of the combined flow. Samani and Mazaheri (2007) presented a new physically based approach for estimating the stage discharge relationship of combined flow over the weir and under the gate for semi submerged and fully submerged conditions. Al-Suhili and Shwana(2013) had obtained a neural networks model for the discharge coefficient of a Cipoletti weir with rectangular bottom opening.

In this study the sediment removal efficiency from both the upstream and downstream sides of the weirs are investigated. Three types of weirs are investigated for the purpose of comparison, weir without any opening, weir with one bottom opening, and weir with three bottom openings, one at the mid of the section and one on each side of the weir section. The aim is to find a relationship between these removal efficiencies with the geometrical and flow variables in non-dimensional forms. This relationship will be found by fitting a suitable model to the experimental data measured hereafter for this purpose.

2. Experimental Setup

Experiments are performed at the Hydraulic Laboratory in Al-Najaf technical institute-civil techniques department. The experiments were carried out in a (17) m long horizontal flume channel (slope equal zero) of cross section (0.5) m width and (0. 5) m height. The channel consisted of glass walls and a stainless steel floor. Two movable carriages with point gauges were mounted on brass rails at the top of the flume sides see Fig.(1).Thirty-three combined weir models were manufactured from a 10mm thick glass, details of these models are shown in table (1) and Fig. (1). For discharge measurements, a full width thin-plate sharp-crested rectangular weir fixed at the tail end of the channel section, was used. The head upstream of the weir and head over the weir, were measured with a precision point gauges whose least count was (0.1) mm .In order to find a more realistic equilibrium scour time, three preliminary tests was made for the combined weir and openings models. It was found that almost 90 percent of maximum scour depth was achieved after a run time of 120 minutes. During each run of experiment, the maximum depth of scour was measured at given time intervals. The experiments shows that two scour holes are created, one at the upstream side of the weir and the other at the downstream side. The shape of each of these two holes is approximately a half ellipsoid. The removal efficiencies are calculated using the difference in sediment volumes before and after operation of the weir model. The volume before is the area of the section that contain the half ellipsoid multiplied by the initial depth of sediment, while volume after operation is the residual volume of this section, which is the volume before operation reduced by the volume of the half ellipsoid. The volume of the half ellipsoid was calculated using the measured three major axis of the hole, after operation.

3. Dimensional analysis for sediment movement

In order to obtain a dimensionless variables model fitted to the experimental data dimensional analysis was performed as follows:

It is expected that the maximum scour depth, maximum scour length and maximum scour width of the three types of models and flow conditions mentioned above are dependent on the geometry of the models as well as on the flow conditions, the following parameters may be considered:

$D_s= f(Q,v,D_{50},\Delta H,g, \rho,\mu , \rho_s, S_o, b_o,h_o,W,h_1,B_w,P)$ (1)

$L_s = f(Q,v,D_{50},\Delta H,g, \rho,\mu , \rho_s, S_o, b_o,h_o,W,h_1,B_w,P)$ (2)

$W_s= f(Q,v,D_{50},\Delta H,g, \rho,\mu , \rho_s, S_o, b_o,h_o,W,h_1,B_w,P)$ (3)

Where:

D_s is the maximum scour depth(m); L_s is the maximum scour length (m) ;W_s is the maximum scour width (m); Q is the water discharge through the flume(m^3/s); v is flow velocity(m/s) ;$D_{50}$is mean sediment (soil) particle diameter(mm) ;ΔH is the difference between the water levels upstream and downstream of the weir (m); g :is gravitational acceleration (m/s^2);ρ is the water density (kg/m^3);μ is the water viscosity (pa.s); ρ_s is the soil particle density(kg/m^3); S_o is flume bed slope; B is flume width(m); h_o, and b_o are the length and width of each opening respectively(m); h_1 is the water height over the weir crest(m); B_w is the width of the weir(m); P the is the weir height(m).

- ***Models type (1)**:*This model is for the case of the weir without bottom openings ,hence, b_o, and h_o can be dropped so the formula can be expressed as:

$D_s/D_{50} =f(R_N, Fr, B_w/\Delta H, h_1/\Delta H, P/\Delta H, B/\Delta H)$ (7)

$L_s/D_{50}= f(R_N, Fr, B_w /\Delta H ,h_1/\Delta H,P/\Delta H, B/\Delta H)$ (8)

$W_s/D_{50} = f(R_N, Fr, B_w /\Delta H ,h_1/\Delta H,P/\Delta H, B/\Delta H)$ (9)

Where: D_s/D_{50} is the relative depth of the scour hole; L_s/D_{50} is the relative length of the scour hole; W_s/D_{50} is the relative width of scour hole Fr is the Froude no; R is the Reynolds no.

- ***Models type(2) and Models type(3)**:*These model are for the two cases of weir with one and three bottom openings , respectively ,where the following formula can be obtained:

$D_s/D_{50}=f(R_N, Fr, B_w /\Delta H ,h_1/\Delta H,P/\Delta H, B/\Delta H, h_o/\Delta H ,b_o/\Delta H)$ (10)

$L_s/D_{50}= f(R_N, Fr, B_w /\Delta H ,h_1/\Delta H,P/\Delta H, B/\Delta H, h_o/\Delta H ,b_o/\Delta H)$ (11)

$W_s/D_{50}=f(R_N, Fr, B_w /\Delta H ,h_1/\Delta H,P/\Delta H, B/\Delta H, h_o/\Delta H ,b_o/\Delta H)$ (12)

As mentioned before, it is observed in the experiments that the scour phenomena at upstream and downstream side of the weir models are characterized each by a hole of half-ellipsoidal shape. The axis along the flow is designated by $L_{Su/s}$,

$L_{Sd/s}$, and across the flow by $W_{Su/s}$, $W_{Sd/s}$ and vertical half axis as $D_{Su/s}$, $D_{Sd/s}$, for the upstream and downstream sides, respectively.

If these values are measured, the volume of that scour hole can be calculated as follows:

$V_{o(u/s)}= 0.5 * (4/3) * \pi (L_{Su/s}) *W_{Su/s} *D_{Su/s}$ (13)

$V_{o(d/s)}= 0.5 * (4/3) * \pi (L_{S\,d/s}) *W_{Sd/s} *D_{Sd/s}$(14)

$V_{s(u/s)}$ = volume of half –ellipsoidal at upstream side of the weir,

$V_{s(d/s)}$ = volume of half –ellipsoidal at downstream side of the weir

If $V_{o(u/s)}$ is the volume of region before scour at the upstream side; $V_{o(d/s)}$ is the volume of region before scour at the downstream side; then:

Removal Efficiency $(RE)_{u/s} = (V_{s\,(u/s)}/ V_{o(u/s)})\%$ (15)

Removal Efficiency $(RE)_{d/s} = (V_{s\,(d/s)}/ V_{o(d/s)})\%$ (16)

These $(RE)_{u/s}$,$(RE)_{d/s}$, will then be affected by the flow and geometric variables.

4. Scour measurements for calculating sediment Removal Efficiency

To investigate the relationship between the removal efficiency at each upstream and downstream side with the relevant flow and geometrical variables for one or three bottom openings models, many experiments were conducted, The summary of results for these experiments are shown in Tables (2 to7) for flow cases No.(2) and No.(3). Investigating these results it is observed that , for both models ,as the flow rate increases, the removal efficiencies (RE) increase . Moreover, it is found also that both removal efficiencies (RE) are increased to almost three times, as the number of opening are increased ,form 1 to 3. As the size of opening increase the removal efficiencies are also increase. However, it can be observed that the best removal efficiency (RE) was achieved for each flow case , at model which have higher values of crest width (B_w) and weir height(P) for the same flow and same number of opening size for each upstream and downstream sides .

5. Application of Two Dimensional Modeling (RMA2)

To investigate the velocity distribution at the upstream and downstream sides of the structure, the software (RMA2) is used. This software was applied for flow case2 only, with two classified cases, case A for one bottom opening, and case B with three bottom openings. Three different dimensions of the openings for each case was selected as shown in Table (8), since for this situation the flow can be approximated by a two dimensional model.

Figures (2,3,and 4) show the velocity distribution at the upstream and downstream sides of the weir for the cases A mentioned previously in Table (8).For the cases of one bottom opening only, it is shown from the velocity contours that an ellipse of a relatively high velocity exists near the opening with maximum velocity just at the opening and decreasing in the direction of the upstream side. The velocity distribution pattern indicates the simulation of flushing of the sediments accumulated upstream the weir from the central part of the channel section rather than accumulated all over the section for the case of normal weir without bottom openings.

Figures (5,6 and7) shows the same analysis for the cases B, mentioned in table(8), which are for a weir with three bottom openings. It is shown from the velocity contours that high velocities exists near the three openings at center and both sides which means more removal efficiency at upstream and downstream sides more than one opening as shown in case A.

6. Artificial Neural Network modeling

An artificial neural network model (ANN), is a mathematical model that is inspired by the structure and/or functional aspects of biological neural networks. A neural network consists of an interconnected group of artificial neurons, and it processes information using a connectionist approach to computation. The artificial neural network models for estimating the scour volumes presented by the following variables{$D_s/D_{50(u/s)}$, $D_s/D_{50(d/s)}$, $L_s/D_{50(u/s)}$, $L_s/D_{50(d/s)}$, $W_s/D_{50(u/s)}$,$W_s/D_{50(d/s)}$, $RE_{(u/s)}$, $RE_{(d/s)}$} as a function of the following variables(B_w /ΔH ,h_1/ΔH,P/ΔH, B/ΔH, h_o/ΔH, b_o/ΔH),were developed using the "SPSS , version 19"software, this software allows the modeling with different network architecture, and use back propagation algorithm for adjusting the weights of the model.

a. ANN Models for weir without openings

As mentioned before, The software needs to identify the input layer which have four variables for this case (nodes)(B_w/ΔH,h_1/ΔH, P/ΔH, B/ΔH) and the number of output variables (nodes) which are here selected as three variables ($D_s/D_{50(u/s)}$, $L_s/D_{50(u/s)}$,$RE_{(u/s)}$). These input-output variables were used in the software and different trials were made to find the most suitable model. The modeling application of this case results indicated that the best ANN model requires only one hidden layer with one node. The best observed activation functions are the hyperbolic tangent and the identity for the hidden and output layers respectively. The correlation coefficients between the observed and predicted three output variables mentioned above, are (0.951, 0.962, and 0.971), respectively which indicates the capability of the model for precise prediction of these variables. Figure (8) shows the architecture of the network.

b. ANN Models for weir with one bottom opening

In this case, the input layer has six variables (nodes)(B_w /ΔH ,h_1/ΔH,P/ΔH, B/ΔH, h_o/ΔH ,b_o/ΔH) and the output layer has eight variables(nodes) which are{$D_s/D_{50(u/s)}$,$L_s/D_{50(u/s)}$,$W_s/D_{50(u/s)}$,$RE_{(u/s)}$, $D_s/D_{50(d/s)}$,$L_s/D_{50(d/s)}$,$W_s/D_{50(d/s)}$, $RE_{(d/s)}$}.The modeling application of this case results indicated that the best ANN model requires one hidden layer with three nodes. The best observed activation functions are the hyperbolic tangent and the identity for the hidden and output layers respectively. The correlation coefficients between the observed and predicted six output variables mentioned above range (0.848 to 0.894), as shown in table(9),which are considered strong according to smith(1993) criteria. Figure (9) shows the architecture of the network.

c. ANN Models for weir with three bottom openings

In this case, the input layer which has six variables (nodes)(B_w /ΔH, h_1/ΔH,P/ΔH, B/ΔH, h_o/ΔH ,b_o/ΔH) and the output layer has eight (nodes) which are {$D_s/D_{50(u/s)}$,$L_s/D_{50(u/s)}$,$W_s/D_{50(u/s)}$,$RE_{(u/s)}$, $D_s/D_{50(d/s)}$,$L_s/D_{50(d/s)}$,$W_s/D_{50(d/s)}$, $RE_{(d/s)}$}.The modeling application of this case results indicated that the best ANN model requires one hidden layer with six nodes. The best observed activation functions are the hyperbolic tangent and the identity for the hidden and output layers respectively. The correlation coefficients between the observed and predicted six output variables mentioned above range (0.803 to 0.888) as shown in table (10), which are considered strong according to smith(1993) criteria. Figure (10) shows the architecture of the network.

7. Conclusions

From that experimental work and modeling analysis conducted in this research, the following conclusions could be deduced:

1. For all the cases tested the coefficients of variation for the estimated removal efficiency of sediments at the upstream and the downstream sides of the weir proposed were (1.113 - 0.465), which indicate the necessity for obtaining a model to describe this variation.

2. The correlation coefficients for the ANN models developed herein were in the range of (0.989-0.803), which can be considered as very good correlations.
3. The obtained velocity distribution of the weir for the flow cases no. 2 with three openings as obtained by using the (RMA2) software, indicates the existence of a high velocity regions at the vicinity of the mid and side openings, rather than that observed for the case of one mid opening ,which indicates only one mid region of high velocity. This will assure better removal efficiency for the case of three openings than the case of one opening.
4. For weir models without openings, the removal efficiency ($RE_{(u/s)}$) in the upstream side was found to be affected significantly by ($B/\Delta H$) and ($h_1/\Delta H$). While for weir models with one middle bottom opening, the removal efficiency in both sides ($RE_{(u/s)}$, $RE_{(d/s)}$) were found to be significantly affected by ($h_1/\Delta H$) . For the weir models with three openings, the removal efficiency in the both sides ($RE_{(u/s)}$, $RE_{(d/s)}$) were found to be significantly affected by ($h_1/\Delta H$, $b_o/\Delta H$), hence, ($h_1/\Delta H$) can be considered as the common effective variable in all cases.

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Table (1) Schematic presentation of sediment Models Tested.

Bottom Openings (b_o x h_o) cm			Crest length (B_w) cm	Crest height ($P=h_o+d$) cm	Model classification	
right	middle	left				
5*10	5*10	5*10	*20*	*20*	*1.a.1*	1.a
10*10	10*10	10*10			*1.a.2*	
10*5	10*5	10*5			*1.a.3*	
10*8	10*8	10*8			*1.a.4*	
8*8	8*8	8*8			*1.a.5*	
5*10	5*10	5*10	*23*	*24*	*1.b.1*	1.b
10*10	10*10	10*10			*1.b.2*	
10*5	10*5	10*5			*1.b.3*	
10*8	10*8	10*8			*1.b.4*	
8*8	8*8	8*8			*1.b.5*	
5*10	5*10	5*10	33	28	*1.c.1*	1.c
10*10	10*10	10*10			*1.c.2*	
10*5	10*5	10*5			*1.c.3*	
10*8	10*8	10*8			*1.c.4*	
8*8	8*8	8*8			*1.c.5*	

Table (2) Relation between removal efficiency and head for flow case no. (2), with B_w=20 cm and p=20 cm.

%Removal Efficiency$(RE)_{(d/s)}$		%Removal Efficiency$(RE)_{(u/s)}$		H (cm)	opening size(cm) (b_o*h_o)
Three openings	One opening	Three openings	One opening		
21.98	7.70	18.76	7.75	12	(10*10)
30.84	18.42	33.16	13.61	14	
37.19	25.68	47.62	19.93	18	
14.30	10.01	13.96	5.23	12	(10*8)
20.34	17.87	23.11	12.52	14	
31.70	24.96	47.48	16.64	18	
4.81	2.05	9.38	3.07	12	(5*10)
11.05	5.99	21.10	9.80	14	
24.65	9.96	35.59	16.01	18	

Table (3) Relation between removal efficiency and head for flow case no. (2) , with B_w=23 cm and p=24 cm.

%Removal Efficiency$(RE)_{(d/s)}$		%Removal Efficiency$(RE)_{(u/s)}$		H (cm)	opening size(cm) (b_o*h_o)
Three openings	One opening	Three openings	One opening		
23.03	13.56	35.17	12.73	12	(10*10)
32.70	22.92	48.26	19.62	14	
39.46	25.68	70.34	38.52	18	
16.69	10.27	16.19	9.63	12	(10*8)
21.58	20.51	26.19	20.24	14	
32.24	24.62	50.80	27.52	18	
9.12	2.25	9.42	5.23	12	(5*10)
14.25	6.03	23.24	15.24	14	
25.00	10.23	36.28	23.49	18	

Table (4) Relation between removal efficiency and head for flow case no. (2), with B_w=33 cm and p=28 cm.

%Removal Efficiency(RE)$_{(d/s)}$		%Removal Efficiency(RE)$_{(u/s)}$		H	opening
Three openings	One opening	Three openings	One opening	(cm)	size(cm) (b_o*h_o)
45.59	13.90	49.75	22.89	12	(10*10)
50.01	24.56	64.47	26.24	14	
61.22	40.22	78.15	41.03	18	
16.60	10.36	28.47	10.59	12	(10*8)
24.32	20.76	40.41	21.88	14	
33.73	28.33	57.39	29.03	18	
11.13	4.30	11.72	7.03	12	(5*10)
21.98	11.40	32.62	22.19	14	
39.05	19.74	55.12	46.22	18	

Table (5) Relation between removal efficiency and head for flow case no. (3)with B_w=20cm,p=20 cm

%Removal Efficiency(RE)$_{(d/s)}$		%Removal Efficiency(RE)$_{(u/s)}$		h	Opening
Three openings	One opening	Three openings	One opening	Over weir	size(cm) (b_o*h_o)
53.50	48.84	74.73	43.26	1.5	(10*10)
63.96	58.15	95.53	60.41	2.8	
50.01	40.01	60.71	37.40	1.5	(10*8)
63.96	55.26	77.45	58.03	2.8	
48.84	38.30	52.33	37.23	1.5	(5*10)
59.31	48.84	74.31	46.05	2.8	
40.82	38.73	41.10	20.64	1.5	(10*5)
51.17	46.52	57.22	33.41	2.8	
44.45	37.61	50.59	23.86	1.5	(8*8)
55.82	46.52	61.40	43.71	2.8	

Table (6) Relation between removal efficiency and head for flow case no. (3)with B_w=23cm,p=24 cm

%Removal Efficiency(RE)$_{(d/s)}$		%Removal Efficiency(RE)$_{(u/s)}$		h	Opening
Three openings	One opening	Three openings	One opening	Over weir	size(cm) (b_o*h_o)
58.01	49.64	79.44	48.57	1.5	(10*10)
67.41	59.31	97.97	71.38	2.8	
56.99	47.08	65.94	44.66	1.5	(10*8)
67.45	58.15	81.12	64.40	2.8	
56.52	43.74	54.43	42.56	1.5	(5*10)
63.96	58.15	78.50	66.76	2.8	
46.05	41.87	43.26	24.28	1.5	(10*5)
58.15	52.33	65.94	38.18	2.8	
46.52	42.98	52.37	40.81	1.5	(8*8)
62.80	56.99	70.34	53	2.8	

Table (7) Relation between removal efficiency and head for flow case no. (3)with B_w=33cm,p=28 cm.

%Removal Efficiency$(RE)_{(d/s)}$		%Removal Efficiency$(RE)_{(u/s)}$		h Over weir	opening size(cm) (b_o*h_o)
Three openings	One opening	Three openings	One opening		
74.43	58.15	87.78	72.29	1.5	(10*10)
81.41	65.13	97.69	96.29	2.8	
60.30	53.38	81.81	60.64	1.5	(10*8)
78.97	64.30	87.78	72.39	2.8	
58.15	52.33	75.01	57.27	1.5	(5*10)
74.43	62.80	84.78	66.99	2.8	
50.24	49.19	49.75	41.87	1.5	(10*5)
67.45	58.15	73.48	61.96	2.8	
50.59	51.36	62.80	43.26	1.5	(8*8)
70.94	61.64	81.95	66.32	2.8	

Table (8) The required boundary conditions for flow case no. (2)classification used in RAM2.

Downstream Boundary Condition Water Depth(m)	Upstream Boundary Condition Discharge (m^3/sec)	No. and size of openings (cm)	Classification
0.011	0.021	1(10*10)	A
0.011	0.021	1(5*10)	
0.011	0.021	1(8*8)	
0.011	0.062	3(10*10)	B
0.018	0.062	3(5*10)	
0.018	0.062	3(8*8)	

Table(9) Correlation coefficients between observed and predicated outputs for the ANN model for the case of weir with one opening.

Correlation Coefficient	Output variable
0.881	$D_s/D_{50(u/s)}$
0.848	$L_s/D_{50(u/s)}$
0.883	$W_s/D_{50(u/s)}$
0.876	$D_s/D_{50(d/s)}$
0.855	$L_s/D_{50(d/s)}$
0.894	$W_s/D_{50(d/s)}$
0.868	$RE_{(u/s)}$
0.894	$RE_{(d/s)}$

Table (10) Correlation coefficients between observed and predicated outputs for the ANN model for the case of weir with three openings.

Correlation coefficient	Output variable
0.822	$D_s/D_{50(u/s)}$
0.803	$L_s/D_{50(u/s)}$
0.868	$W_s/D_{50(u/s)}$
0.835	$D_s/D_{50(d/s)}$
0.888	$L_s/D_{50(d/s)}$
0.886	$W_s/D_{50(d/s)}$
0.803	$RE_{(u/s)}$
0.801	$RE_{(d/s)}$

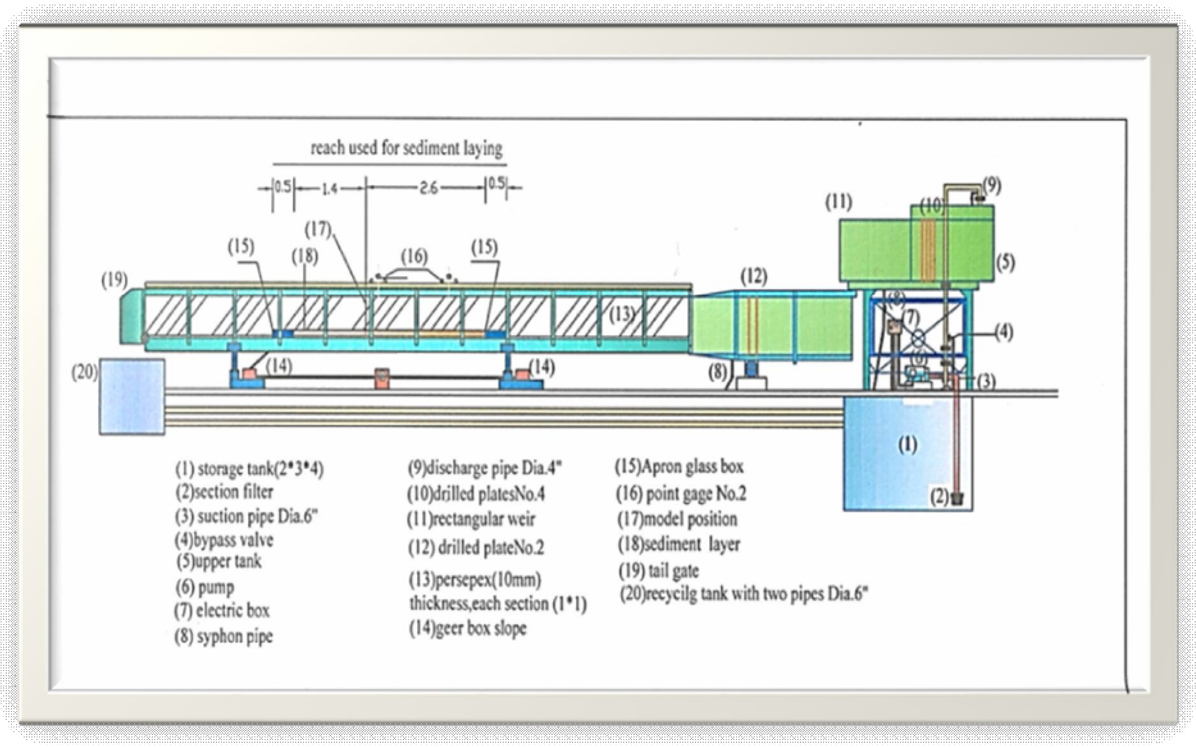

Figure (1) Schematic Diagram of channel side with details.

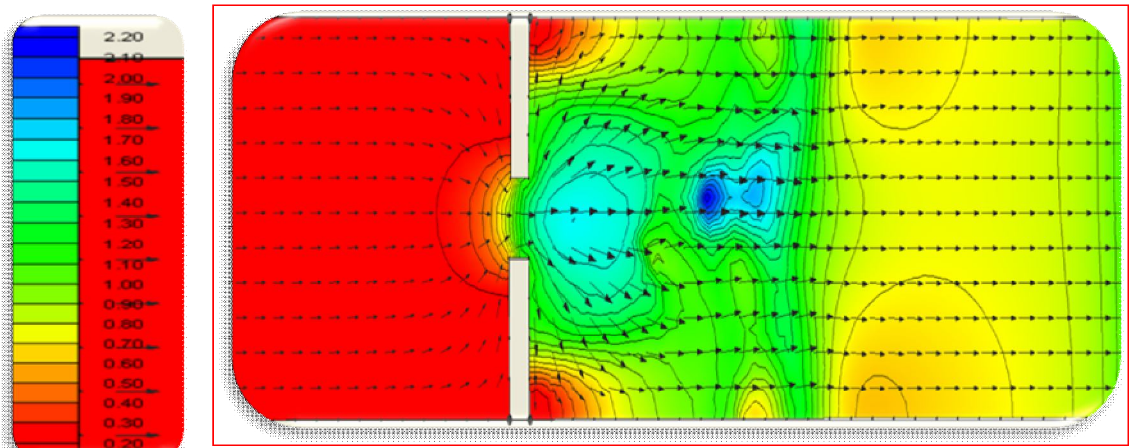

Figure (2) case A, weir with one opening (10*10) cm

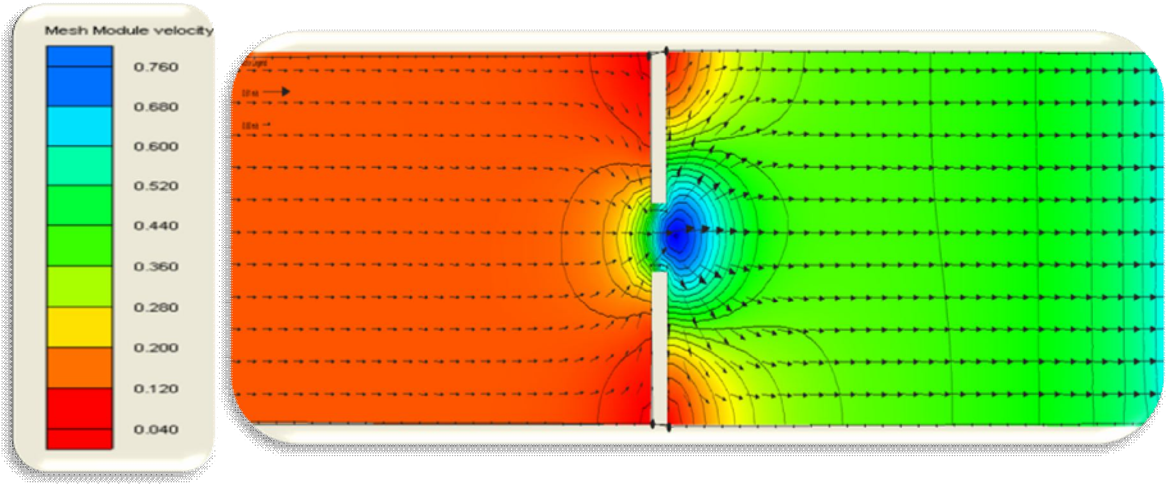

Figure (3) case A, weir with one opening (8*8) cm

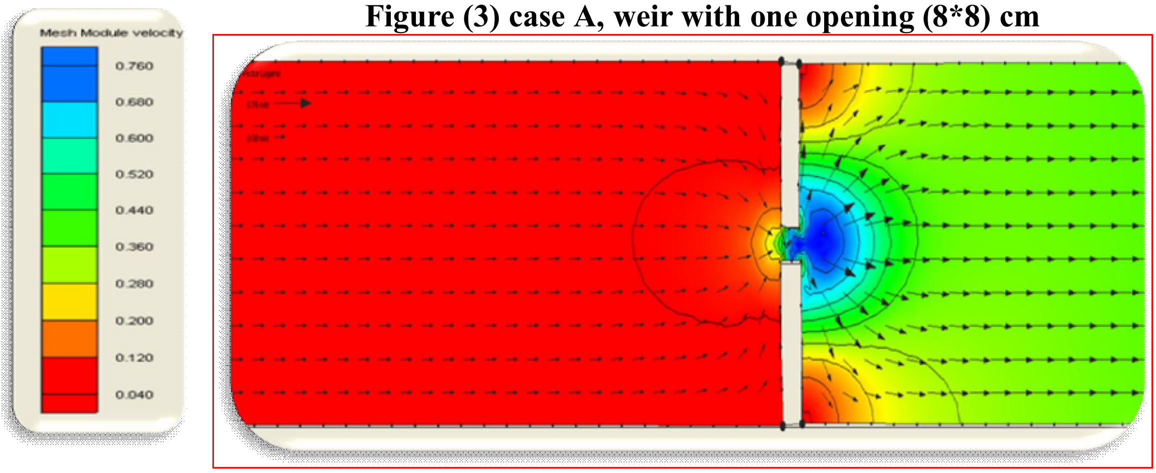

Figure (4) case A, weir with one opening (5*10) cm

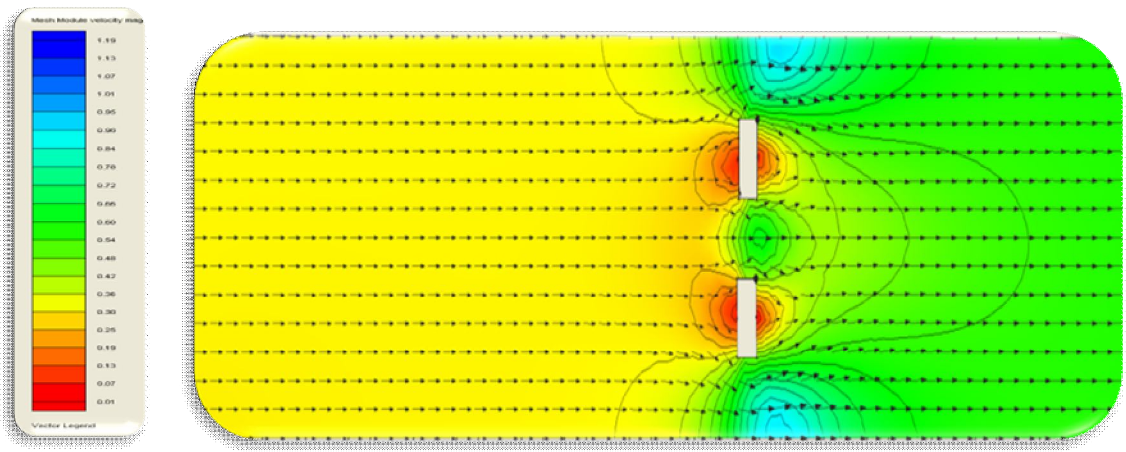

Figure (5) case B, weir with three opening, each is (10*10) cm

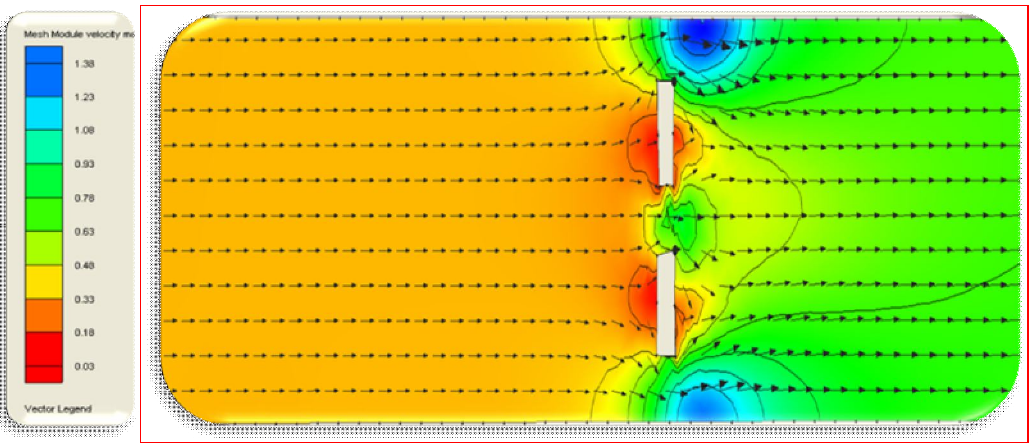

Figure (6) case B, weir with three opening ,each is (8*8) cm

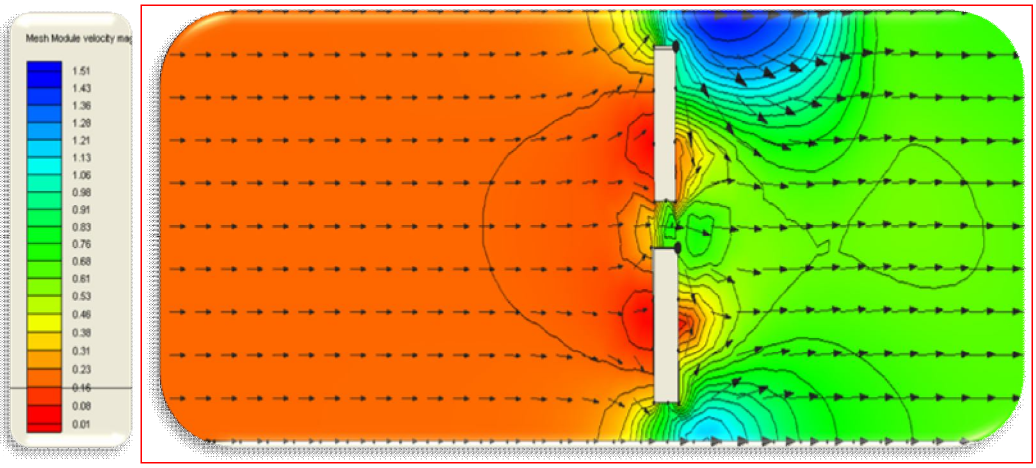

Figure (7) case B, weir with three opening, each is (5*10) cm

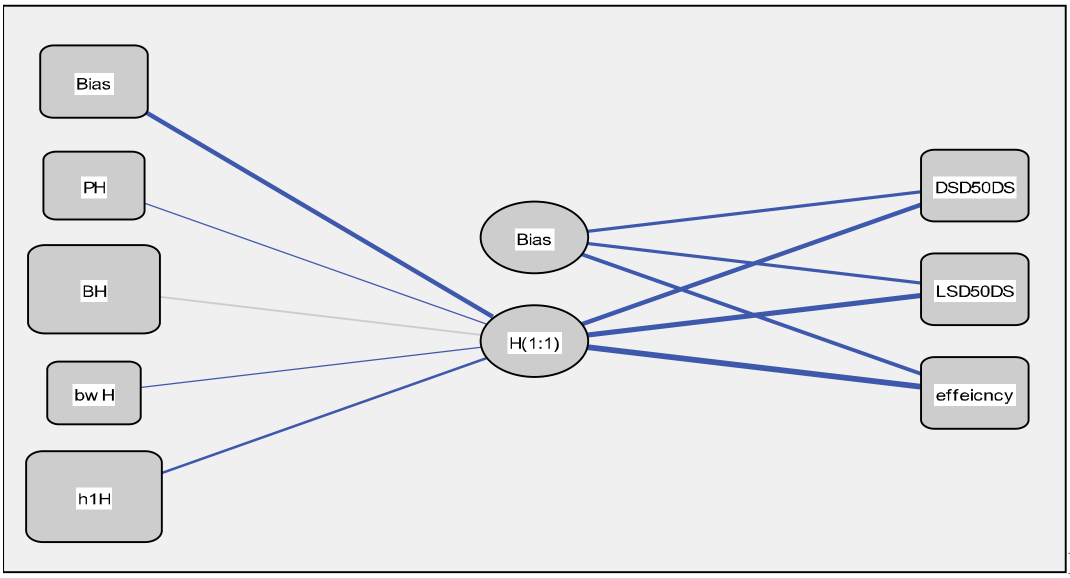

Figure (8) ANN model architecture for weir without openings with correlation coefficients (R=0.951) (R=0.962), (R=0.971).

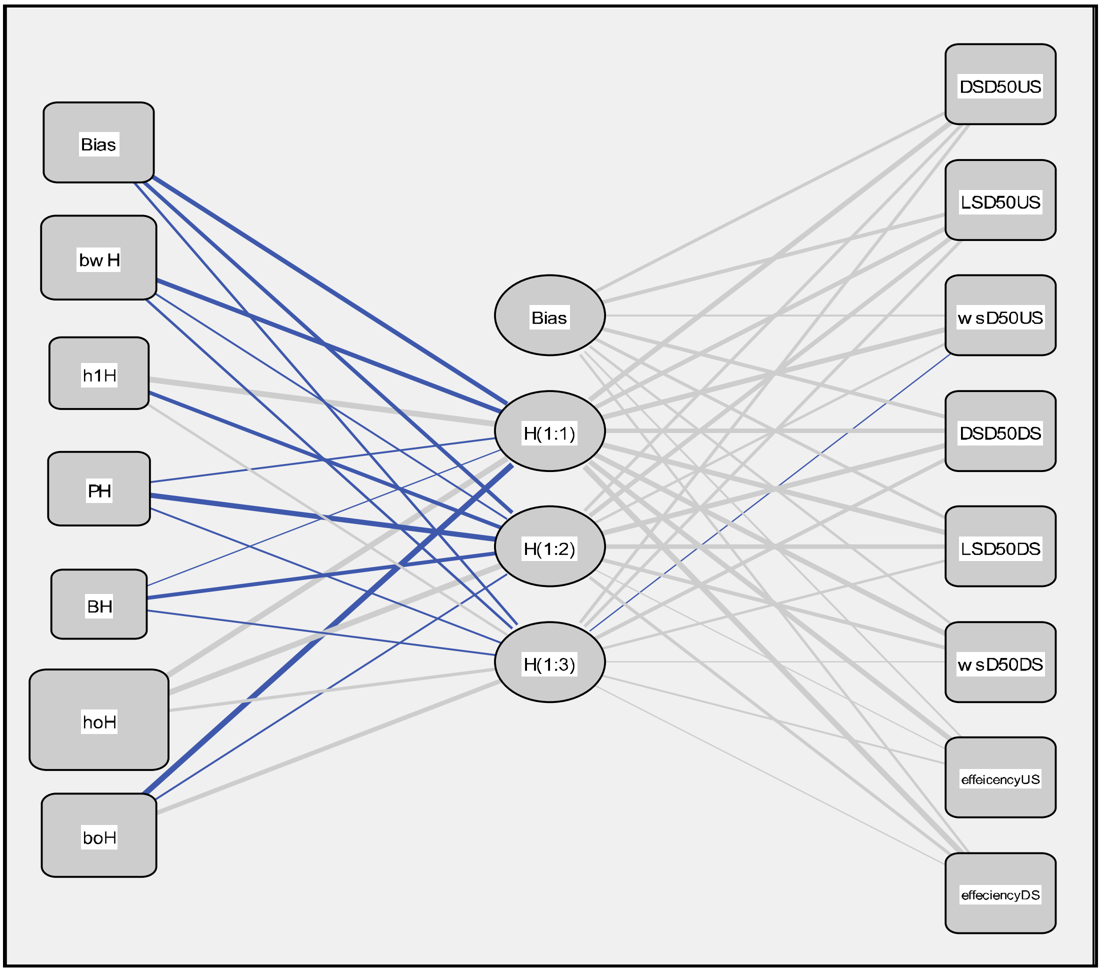

Figure (9) ANN model architecture for weir with one bottom opening with correlation coefficients shown in table(8).

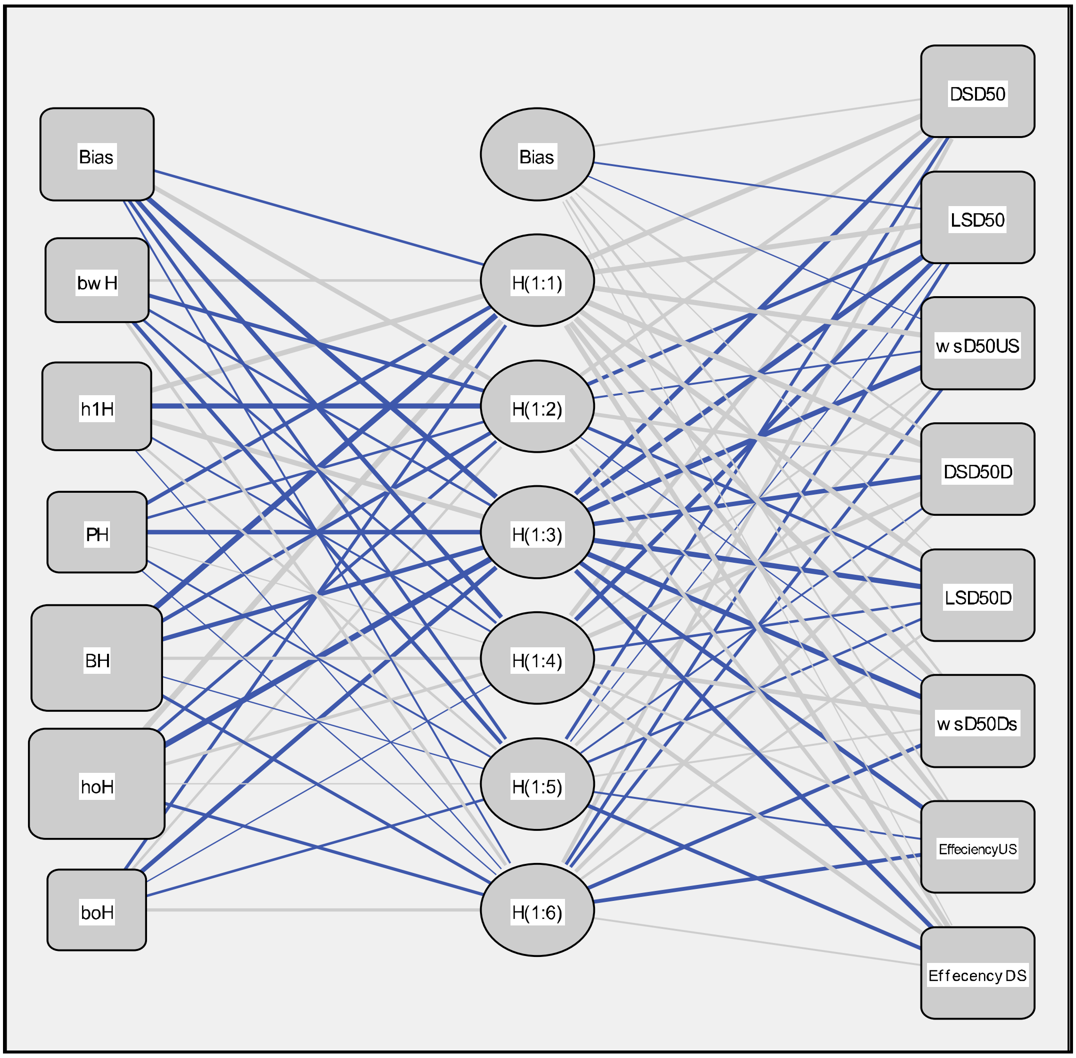

Figure (10) ANN model architecture for weir with three bottom openings, with correlation coefficients shown in table(9).