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RESEARCH ARTICLE

Physical, Chemical Science and Engineering: ARTIFICIAL NUREL NETWORK MODELLING OF FLOW OVER WEIR.

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Abstract

Prediction and modeling of hydraulic phenomenon is an important part of hydraulic engineering activities. One of the applications of prediction and modeling is estimating the discharge coefficient for hydraulic structures. Weirs and spillways build for passing water flow in critical conditions or for regulating the water surface elevation. The most common types of weir crest in the practice are broad-crested weir, step broad crested weir and ogee crest weir. These structures are installed for measuring or regulating rate of flow in open channels. A broad crested weir is an overflow structure with horizontal crest above which the streamlines are nearly straight and parallel. This study presents a series of experimental investigations on flow over broad crested weir to find the hydraulic characteristics of the flow. Computer modeling of hydraulic characteristics for weir includes the calculation of water surface profiles and estimating the discharge coefficient (**C**d). There are several ways to estimate the (**Cd)**, such as experimental formulas and computational intelligence techniques. For this purpose, the physical model of broad-crested weir with rectangular channel cross-sections was tested for a different range of discharge values. The experimental results were yielded to find discharge coefficient by using the dimensional analysis. Then, the results obtained were applied with artificial neural network (ANN) techniques to investigate the applicability, ability, and accuracy of these procedures. Comparison of result from ANN procedures with these of experimental results clearly indicates that the ANN technique is efficient for the determination of discharge coefficient.

Introduction:-

Measurement of discharge in open channels is one of the major requirements for the hydraulic engineers. Broad crested weirs are commonly used to compute discharge in open channels and the laboratories by measuring the water head upstream of the crest of the weir. Many researchers have made extensive studies on rectangular weirs and have contributed to the development of various formulae, which have been proposed for the discharge

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calculation. [12,7]. It is essential to predict discharge coefficient and the discharge correctly by the hydraulic engineers, who are involved in the technical and economical design of weirs. Flow over a broad-crested weir (Fig.1) under free flow condition in a channel is expressed in the following:

$$Q = 2/3\ Cd\ (2g)^{1/2}\ L\ (h)^{3/2} \quad \text{...... (1)}$$

Where Cd = coefficient of discharge, L = crest length of the weir, g = acceleration due to gravity, h = head over the crest. Cd depends on flow characteristics and geometry of the channel and the weir.

Numerical and experimental studies of flow over weirs have a number of applications especially in the analyses of flow over common types of civil engineering structures. The problem of flow over weirs has been extensively studied experimentally. Most of the experimental works were performed to understand the flow characteristics of these weirs as well as the determination of the coefficients of discharge under free and submerged flow conditions [9]. The study of [14] carried out a set of laboratory experiments to investigate the effect of upstream weir rounding on discharge coefficient. [11] performed a set of laboratory experiments to investigate the flow characteristics of broad crested weir with a sharp upstream corner. Based on the work done by [16], rectangular broad crested weir with measurements of free-surface profile over a laboratory-scale was performed and compared with numerical procedures by aiding computer software. [10] mainly focused on hydraulic behavior, flow conditions, and the discharge coefficient for different types of weirs. [6] presented a comprehensive analysis for flow over weirs of finite crest length with square edged or rounded entrance; they observed a good correlation for the (Cd) for a weir with rounded entrance. [8] performed two different artificial neural network (ANN) techniques to lateral outflow over rectangular-side weirs located on a straight channel. They reported that the ANN technique could be employed successfully for the determination of discharge coefficient. He is found that the feed-forward neural network (FFNN) model is to be better than the radial basis neural network. Estimation of energy dissipation of flows on stepped chutes, carried out by [15] using ANN.

The present study aims to explore ability of the ANN model for the estimation of discharge coefficient of a broad-crested weir under free flow conditions in a rectangular channel and show the agreement with the experimental results.

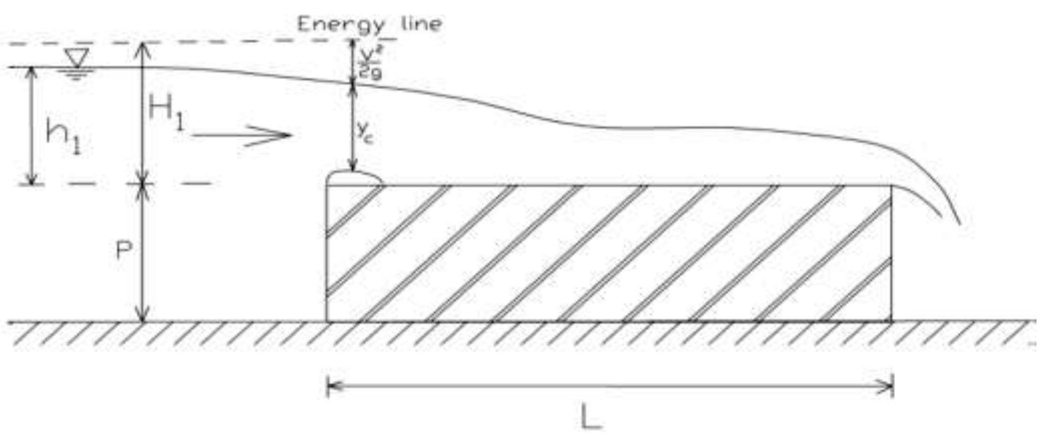

Figure 1:- Sketch of Broad Crested Weir

Experimental work:-

The experiments were conducted at the hydraulic laboratory at Mustansiriayah University, Collage of Engineering in BAGHDAD, IRAQ. The experiments were conducted in a horizontal rectangular channel of 30 cm wide, 30 cm high and the total length of channel was 4.8 m with smooth strong glass supported by stainless steel supporting bars as shown in Fig(2). The broad-crested weir model of height P = 15 cm; length L=36 cm; was manufactured from steel and well-polished to obtain smooth surfaces. It was located at 90 cm downstream of the inlet to ensure the stability and uniformity of water surface levels. The upstream corner of broad crested model was rounded with the radius of curvature R = 0.03 m as shown in Fig. (2). Thus, an excellent, smooth, and wave less flow was obtained that could be analyzed accurately.

Three movable point gauges are installed at the top of the centerline of flume which used to measure water level and they traverse at different static points spaced with 1 mm accuracy. Water was supplied from an electrically pump which was placed in a storage water tank.

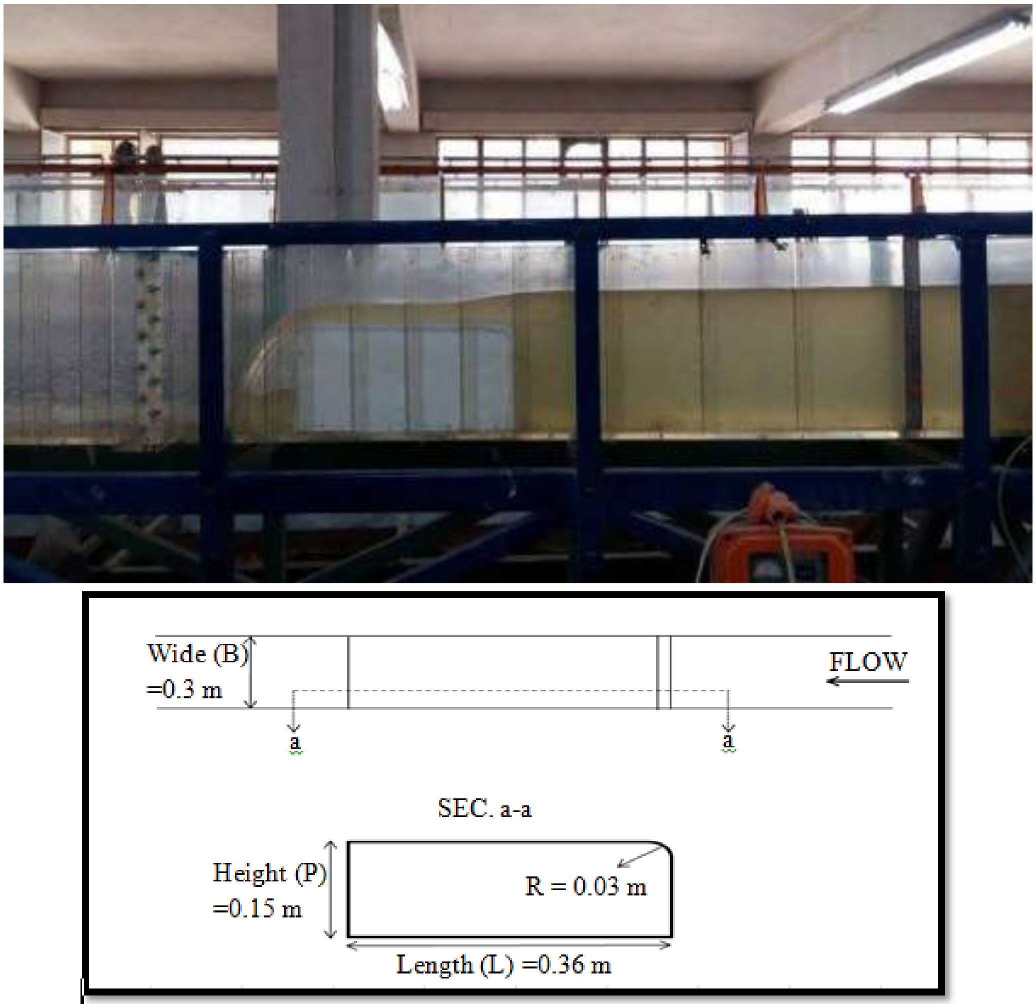

Figure 2:- Photo of Experimental Channel with Broad Crested Weir Model

Material and Methods:-

The data sets resulted from the experimental work have been used for building he model and for validation to assess the potential of the non-linear equation by ANN modelling techniques in order to predict the coefficient of discharge for broad crested weir. The correlation coefficient (r) has been used mainly for the performance evaluation of models and comparison of the results. A higher value of a correlation coefficient and a smaller value RMSE indicate a better performance of the model. Further, measured values of coefficient of discharge have been plotted against the computed values obtained with ANN.

Dimensional analysis:-

First dimensionless factors influence on the weir discharge coefficient extract with using dimensional analysis technique. Referring to Fig. 1 the discharge coefficient (C_d) can be written as a function of width of channel (B), flow depth in the main channel (h), height of weir (P),length of weir (L), acceleration due to gravity (g), dynamic viscosity of water (μ), density of water (ρ).

Using the Buckingham theorem, non-dimensional equations in functional forms can be obtained as below:

$$C_d = f(h/P, h/B, h/L, Re, Fr) \quad \ldots (2)$$

Artificial neural network (ANN):-

A neural network is an artificial intelligence technique that mimics a function of the human brain. The network comprises a large number of simple processing elements linked to each other by weighted connections according to specified architecture. A neuron consists of multiple inputs and a single output. The number of neurons in the input and output layers are fixed by the problem being modeled as the number of input variables equals number of input neurons and number of output variables equal number of output neurons. The determination of optimal number of hidden layers and hidden neurons is usually cumbersome, as no general methodology is available for their determination. These networks learn from the training data by adjusting the connection weights. Of the many ANN paradigms, the feed forward back-propagation neural network (FFBP) is by far the most popular.

In this study, a feed-forward neural network with back propagation learning algorithm is applied. The basic element of a back-propagation neural network is processing node and structure of commonly used back propagation neural network. A neuron consists of multiple inputs and a single output. The sum of inputs and their weights lead to a summation function. The output of a neuron is decided by an activation function, which can be step, sigmoid, threshold and linear etc.

In a back propagation neural network, generally, there is an input layer that acts as a distribution structure for the data being presented to the network. This layer is not used for any type of processing. After this layer, one or more processing layers follow, called the hidden layers. The final processing layer is called the output layer in a network. This process is repeated until the error rate is minimized or reaches to an acceptable level, or until a specified number of iterations have been accomplished. All the interconnections between each node have an associated weight. The values of the interconnecting weights are not set by the analyst but are determined by the network during the training process, starting with randomly assigned initial weights. There are a number of algorithms that can be used to adjust the interconnecting weights to achieve minimal overall training error in multi-layer networks.

Fig. 3, demonstrates a three-layer neural network consisting of inputs layer, hidden layer (layers) and outputs layer. As shown in the fig.3, the wi is the weights and bi is the bias for each neuron. Initial assigned weight values will progressively corrected during a training process that compares predicted outputs to known outputs. Such networks are often trained using back propagation algorithm [2].

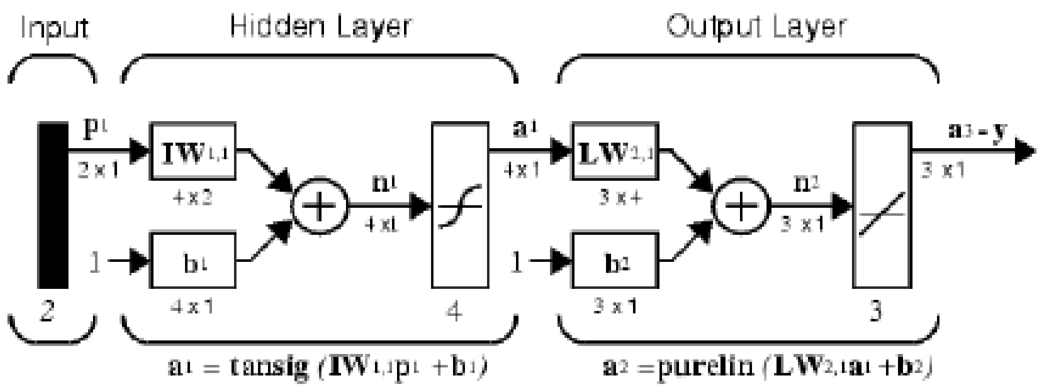

Figure 3:- A three-layer Neural Network [2].

Building of ANN model and the results of the study:-

The ANN model by the Statistical Procedure for Social Science software (**SPSS, version 20**) was utilized for the experimental data, of (input-output) variables. A lot of advantages can be seen by using such software such as the selection of the number of hidden layers, the number of nodes in each hidden layer, the types of activation functions for both hidden and output layers, an initial value for the learning rate and the momentum factor. The most important tool of ANN applied in this study is the multi-layer perceptron (MLP) which is a neural network modeling tool that is optimized for prediction and forecasting applications. [3]

At the first application of the SPSS software low correlation was obtained between the predicted and observed output using the traditional ANN modeling. This was observed through many trials that were performed using different ANN modeling parameters such as changing the data sub-division percent into training, testing and holdout (verification) subsets, different activation functions for the hidden and output layers, different number of hidden nodes in the hidden layer, different learning rates and momentum terms and different number of epochs. In order to check the reason of obtaining low correlation the data set were investigated. It is observed that one of the input variables, namely (h/L) can be only considered as a categorization variable. This variable has a constant value for a group of observations; this means that this variable is working as a factor rather than as a variable, hence, this led to use it as a factor and not a variable in the ANN modeling process.

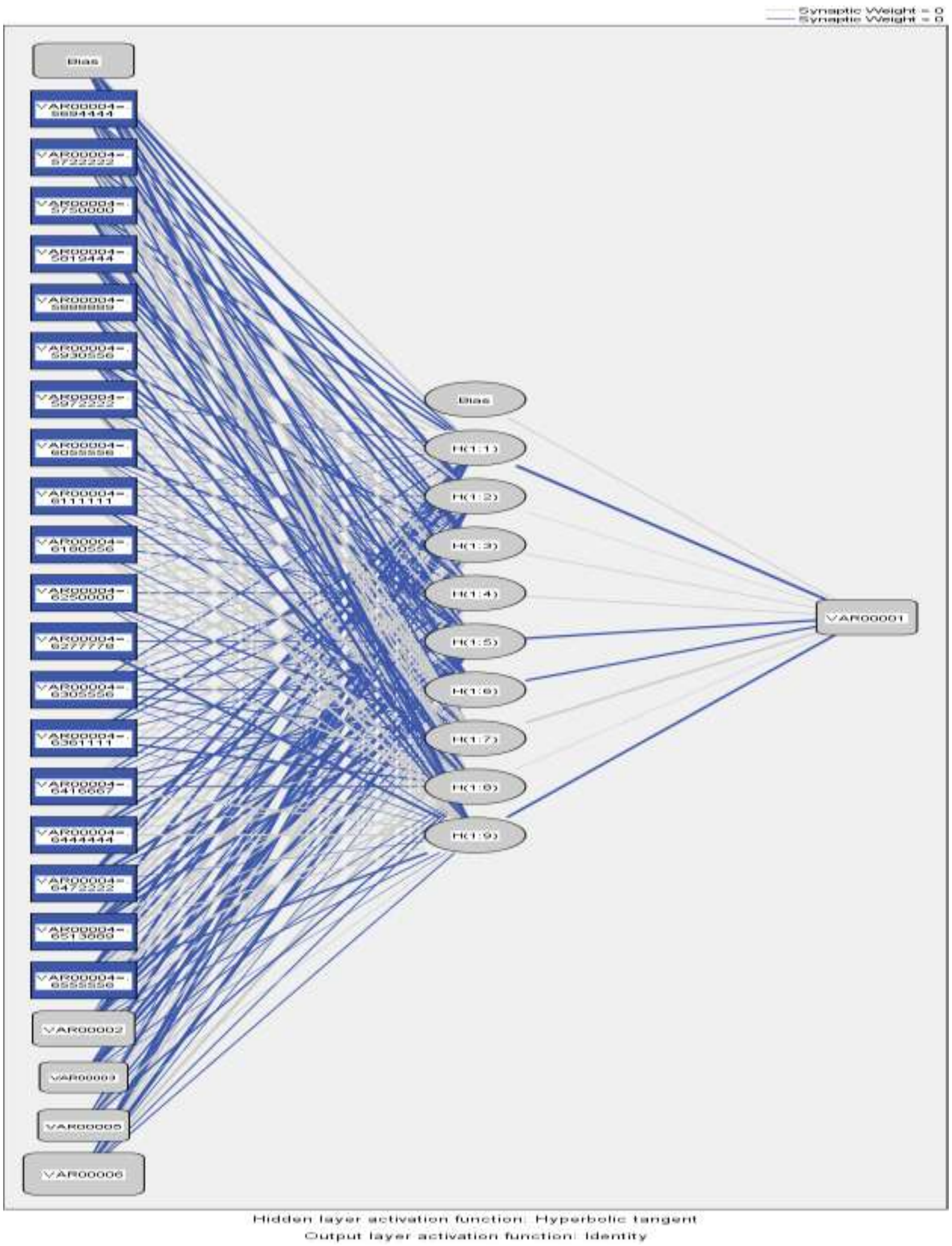

Figure 4:- Layers of ANN Model

An ANN factorized back propagation model was observed, the data division into training set, testing set, and validation (holdout) set. The most suitable data division found here to be 90% for training, 5% for testing, and 5% for validation.

Input layer of 5 neurons to represent the dimensionless variables (h/p, h/B. h/L, Fr, and Re) as shown in the dimensional analysis previously. The output layer represents discharge coefficients (Cd).The model network information which was obtained for this study indicates (9) numbers of hidden nodes in one hidden layer. The obtained required activation function of the hidden layer is Hyperbolic tangent, and the Rescaling Method for Scale Dependents of the output layer is standardized with Identity Activation Function as shown in figure(4). These parameters values were found as the best selected among the different values tried.

Results and discussion:-

1. The ANN architecture model, the selected parameters and the activation function are suitable to relate the (cd) with different variables. Correlation coefficient between the observed and predicted discharge coefficients was (0.92) which can be considered as a very good correlation as shown in figure (5).
2. The variation of (Cd) with each of the variables (h/P, h/B and h/L are shown in Figures (6 to 9), respectively. It can be seen from the figures that single correlation between the Cd and each variable is good, but it expected that multiple correlation for Cd with these variables will be significant. Figure (6) illustrates the variation of discharge coefficients (Cd from Experimental work and Cd from ANN Model) with the value of (h/P) ratio. It is clear from the figure that the discharge coefficient decreases as (h/P) increases.
3. Figure (7) shows the variation of discharge coefficients (Cd from Experimental work and Cd from ANN Model) with the value of (h/B) ratio. It is also shown clearly from the figure that the discharge coefficient decreases as (h/L) increases.
4. The same trend of relationship is shown between (Exp. and ANN Cd) with (h/L) ratio as shown in figure (8).
5. All the flow conditions proposed exhibits Subcritical flow upstream side of the structure, since Froude number range is less than (1). Figure(9).
6. It is shown from the previous figures that there is highest Correlation analysis between the discharge coefficients and the variables involved in this study.
7. From the ANN results, it is shown that the ratio (h/L) has an independent importance of about 61% and the (h/P) has an independent importance of about 54% among the other variables.
8. Froude No. has very big independent importance (100%) as it was expected as shown in table (1).

Table1:- IndependentVariableImportance

Variables	Importance	Normalized Importance
(h/L)	0.236	61.6%
(h/P)	0.205	53.5%
(h/B)	0.072	18.7%
Re	0.102	26.7%
Fr	0.384	100.0%

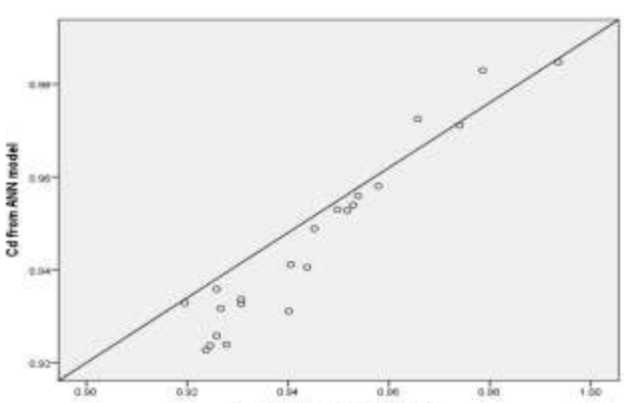

Figure 5:- Relation between Observed and Predicted Cd.

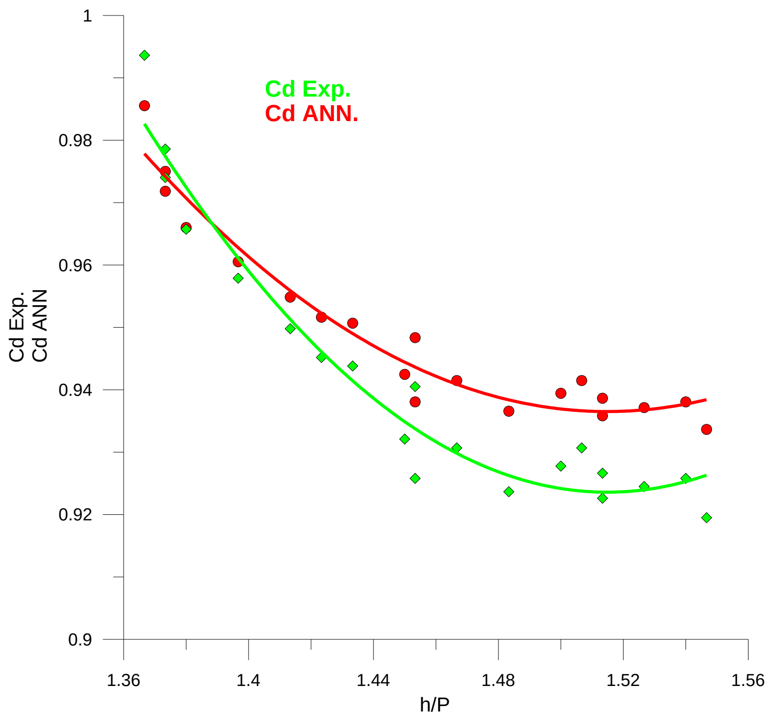

Figure 6:- Relation between (Cd from Experimental and ANN Modeling) with (h/P).

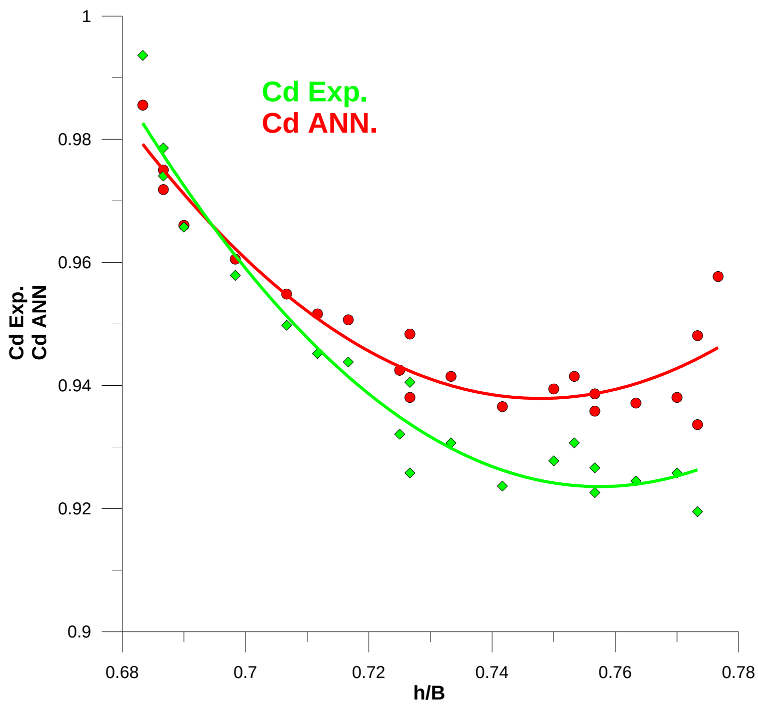

Figure 7:- Relation between (Cd from Experimental and ANN Modeling) with (h/B)

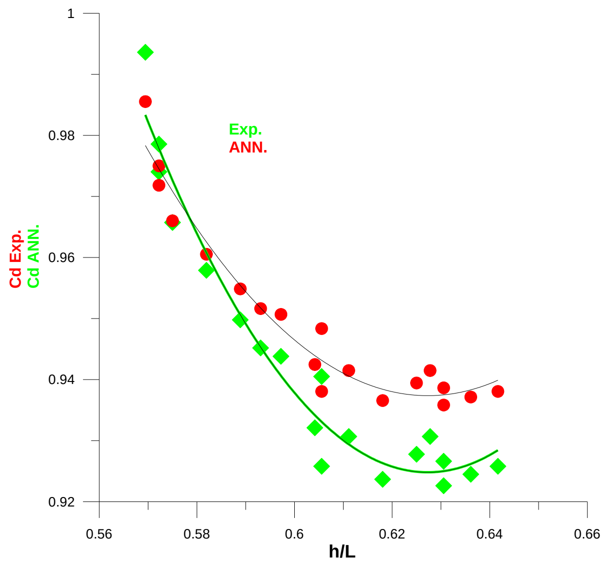

Figure 8:- Relation between (Cd from Experimental and ANN Modeling) with (h/L)

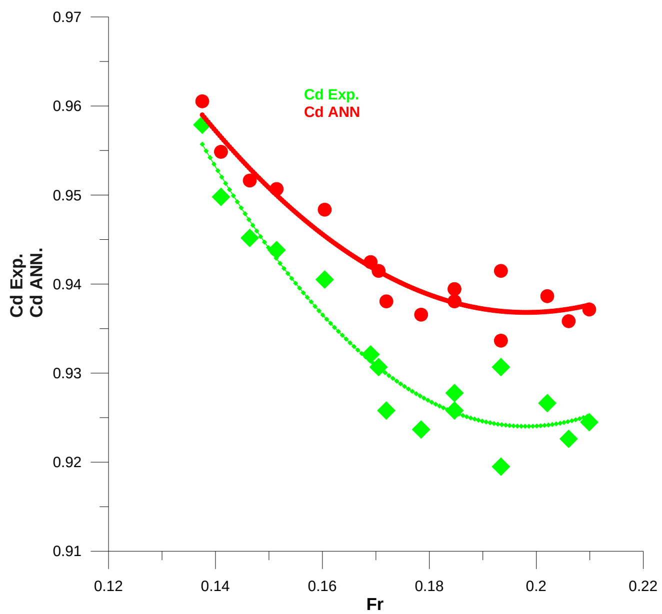

Figure 9:- Relation between (Cd from Experimental and ANN Modeling) with (Fr)

Conclusions:-

The following conclusions are obtained within the range of experimental results and ANN Modeling outputs:

1. Suitable ANN architecture model was concluded with selected parameters and the activation function make a relationship for (cd) with different variables.
2. High Correlation coefficient between the observed and predicted discharge coefficients.
3. (Cd) decreases as the ratios (h/P, h/B and h/L) increases.
4. Good single correlation between the Cd and each variable, but it expected that multiple correlations for Cd with these variables will be significant.
5. The flow condition was Subcritical flow since Froude number range is less than (1).
6. Highest Correlation analysis was concluded between the discharge coefficients and the variables involved in this study.
7. The ratio (h/L) has an independent importance of about 61% and the (h/P) has an independent importance of about 54% among the other variables.
8. 100% independent importance for Fr as it was expected.

Abbreviations:-

A list of symbols that be used in this research are shown below:

Cd the coefficient of discharge
h the experimental head (m)
B the width of the weir (m)
Fr the dimensionless Froude number
L the length of the weir (m)
P the height of the weir (m)
R round edge of upstream edge
Q the actual discharge (m^3/s)
g the gravitational acceleration (m/s^2)
R Reynold number

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