Evaluation of the local scour downstream untraditional bridge piers

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Abstract

The reduction of local scour downstream bridge piers got a massive concentration by several studies. In this study the D/S edge of the rectangular section semicircular bridge pier was reduced. This reduction was built to determine its influence on the local scour D/S these piers. Four models of the piers were manufactured from thermo-stone. The upstream semicircle diameter was fixed by a 10 cm, while the D/S diameter was changed to 4,6,8 and 10 cm . The experimental results provide evidence that the reduce of the D/S diameter of the pier leads to decrease the D/S scour depth and length . Moreover, in its place the sand was noticeably deposited D/S the pier. The experimental results was used to develop two liner empirical relations the first to estimate the ratio of maximum scour depth to U/S diameter of the pier ds/d_1 . While the second to estimate the ratio of the length of scour to U/S diameter of the pier X/d_1 , in terms of the ratio for D/S diameter of the pier to U/S diameter of the pier d_2/d_1 , length of the scour U/S the pier to D/S diameter Z_1/d_2, maximum width of scour to D/S diameter Z_2/d_2 , maximum height of sand deposition D/S of the pier to D/S diameter y/d_2 and Froude number Fr. Furthermore, the two empirical relations were compared with the results of the artificial neural network (ANN). The utilize of ANN techniques yields superior results for predicting the maximum depth and length of scour D/S these piers .

Key words: Hydraulic structures ; Bridge piers ; local scour ; ANN.

تقويم النحر الموضعي مؤخر دعامات الجسور غير التقليدية

الخلاصة

إن تقليل النحر الموضعي مؤخر دعامات الجسور قد اخذ اهتمام كبير من قبل العديد من الدراسات. في هذه الدراسة تم تصغير قطر نهاية الدعامة مستطيلة المقطع ذات النهايات نصف دائرية. أجري هذا التصغير لغرض قياس تأثيره على النحر الموضعي مؤخر الدعامات . تم اختيار أربعة نماذج صنعت من مادة الثرموستون. الجزء نصف دائري مقدم الدعامة وبقطر 10 سم لم يتم تغيره , بينما تم تغير أقطار مؤخر الدعامات وبأقطار 8,6,4 و10سم . أثبتت النتائج المختبرية بأن تصغير قطر مؤخر الدعامة أدى إلى تقليل عمق وطول النحر الموضعي . بالإضافة إلى ذلك , وبدلا عنه

فأن الرمل قد ترسب وبوضوح مؤخر الدعامة. كما استخدمت النتائج المختبرية لاستنباط علاقتين وضعيتين خطيتين الأولى لنسبة العمق الأقصى للنحر إلى قطر مقدم الدعامة ds/d_1 . بينما الثانية لنسبة طول النحر إلى قطر مقدم الدعامة X/d_1 وبدلالة نسبة قطر مؤخر الدعامة إلى قطر مقدمها d_2/d_1 , نسبة طول النحر مقدم الدعامة إلى قطر مؤخرها Z_1/d_2 , نسبة أقصى عرض للنحر إلى قطر مؤخرها Z_2/d_2 , نسبة أقصى ارتفاع لترسيب الرمل مؤخر الدعامة إلى قطر مؤخرها y/d_2 و رقم فرود Fr . بالإضافة إلى ذلك فأنه تم مقارنة العلاقتين الوضعيتين مع نتائج الشبكة العصبية الاصطناعية ANN . أن استخدام تقنيات ANN أعطى تفوق بالنتائج للتنبوء بعمق وطول النحر مؤخر هذه الدعامات.

Introduction

The flow of water in the region of bridge piers in a movable bed channels and rivers causes local scour formed in front and behind these piers. To prevent any serious failure of the bridges , a great attention is needed to reduce the local scour around the bridge piers. Early studies are proposed different ways and methods to protect the river bed by using riprap stones, mats and bags, gabions [1],[2]. Another studies are concentrated on the evaluation of the maximum scour depth , shape and volume of the scour hole.[3] proposed the use of a sacrificial sill, set upstream to the pier, as a countermeasure acting by protecting the pier from the approach flow. (the pier lies in the wake vortex zone, generated at the sill; in this zone, a velocity reduction is observed and, therefore, a local scouring reduction occurs). [4] investigated the effects of inclination of bridge piers on local scour depths around them . They used single circular pier which incline toward the downstream direction in a uniform bed material. These piers were employed near threshold conditions. The results of this study indicated that the local scour depth decreases as the inclination of the pier increases. [5] examined the capability of wire gabions as an alternative protecting device instead of ripraps. This device prevent scour around circular bridge piers in a clear-water condition. [6] presented a study to determine the effectiveness of the splitter plate attached to the pile and the threaded pile (helical wires or cables wrapped spirally on the pile). Therefore, the scour is controlled at circular piles under wave. The results showed that the average reduction of scour depth by the splitter plate was measured as 62%. For threaded piles, various cable–pile diameter ratios were tested and the most efficient cable–pile diameter ratio was found to be 0.75, which reduced scour depth by an average of 51%. The average reductions of scour depths for other cable–pile diameter ratios of 0.33 and 0.5 were 43 and 48%, respectively .The turbulent horseshoe vortex flow within the developing (intermediate stages and equilibrium) scour holes at a circular pier and equilibrium scour holes at a square pier was measured by [7], the imperative observation is that the flow and turbulence intensities in the horseshoe vortex flow in a developing scour hole are reasonably similar. [8] studied the scour at submerged circular cylinders embedded in uniform bed sediments under steady flow. The scour depths were compared with the scour depths at corresponding unsubmerged cylinders of the same diameters under similar flow and bed sediment conditions. The experimental results showed that the scour depth at the submerged cylinders decreases with an increase in submergence ratio. [9] studied the local scour around rectangular section semi-circular nosed pier, under clear water condition and the effect of inclination of pier axis with flow direction. Experiments were conducted using three different models fixed in sandy bed channel. First, the pier axis was parallel to the flow direction, then it was inclined by α= 15° and α= 30°.The results showed that the depth of scour increases with the discharge and angle of inclination of the pier axis with the flow direction. The increase was 17.6% and 19.6% for α = 15° and α = 30° respectively. [10] presented the results from laboratory experiments to investigate the effectiveness of bed sills as countermeasures against local scouring at a smooth circular bridge pier, for flow conditions near the threshold of uniform sediment motion. The bed sill was located downstream of the pier, and its effectiveness with the distance between pier and sill was evaluated. The dependence of the scour depth on different dimensionless groups was defined. The results showed that a bed sill placed at a short distance downstream of the pier reduces the scour depth, area, and volume. In particular, the smaller the distance between the two structures, the larger the effectiveness of the countermeasure. The bed sill seems to take effect some time after the beginning of the test, as the scour hole downstream of the bridge pier develops sufficiently and interacts with the countermeasure.

This study concentrated on the change of the downstream D/S shape of the pier by reducing the diameter of it's semi-circle nose. So, the main objective of this paper is to determine the effect of change the D/S shape of the bridge piers (named untraditional bridge piers) on the local scour in the region of it. Experimental results of the bed scour will be used to develop two regression models for both maximum scour depth and length of the scour D/S the piers. Furthermore, the Artificial neural network (ANN) is used for the purpose of comparison , identification and to predict the scour hole depth and length D/S these types of piers under clear water and steady flow conditions.

Dimensional Analysis

The main parameters that control on the depth and length of scour D/S the bridge pier are placed in a functional forms as :

$$ds = f_1(d_1,d_2,q,g,\rho,d_{50},h,\rho_s,Z_1,Z_2,y) \quad \text{-----------------------------------} \quad (1)$$

$$X = f_2(d_1,d_2,q,g,\rho,d_{50},h,\rho_s,Z_1,Z_2,y) \quad \text{------------------------------------} \quad (2)$$

where:

ds = maximum scour depth D/S the pier, cm
X = length of the scour D/S the pier, cm
d_1 = upstream diameter of the pier, cm
d_2 = downstream diameter of the pier, cm
q = discharge per unit width , $cm^3/s/cm$
g = acceleration due to gravity, cm/s^2

ρ = water density,
d_{50} = median size of sand, mm
h = depth of water, cm
ρ_s = sand density,
Z_1 = length of the scour U/S the pier, cm
Z_2 = maximum width of scour , cm
y = maximum height of sand deposition D/S of the pier , cm

By dimensional analysis, equations (1) and (2) may be formed in nondimensional expression as:

$$ds/d_1 = f_3\,(d_2/d_1\,,\, Z_1/d_2\,, Z_2/d_2\,, y/d_2,\, Fro,\, \rho/\rho_s\,, Fr) \qquad \text{----------------}(3)$$

$$X/d_1 = f_4\,(d_2/d_1\,,\, Z_1/d_2\,, Z_2/d_2\,, y/d_2,\, Fro,\, \rho/\rho_s\,, Fr) \qquad \text{------------------}\ (4)$$

where:

Fro = densimetric particle Froude number
Fr = Froude number
Since;
d_{50} , ρ and ρ_s are fixed , then in accordance with these conditions, the dimensionless scour depth can be reduced to:

$$ds/d_1 = f_5\,(\,d_2/d_1\,,\, Z_1/d_2,\, Z_2/d_2\,, y/d_2,\, Fr) \qquad \text{----------------------}\ (5)$$

$$X/d_1 = f_6\,(d_2/d_1\,,\, Z_1/d_2\,, Z_2/d_2\,, y/d_2,\, Fr) \qquad \text{---------------------}\ (6)$$

The nondimensional parameters d_2/d_1 , Z_1/d_2 ,Z_2/d_2 ,y/d_2 and Fr are considered as the inputs in the present ANN analysis . While the nondimensional parameters ds/d_1 and X/d_1 are considered separately as the outputs.

Experimental Facilities and Procedure

The experiments were carried out in a recirculating laboratory flume with a length of 5.7m, 1.2m width and 0.6m depth . The flume was connected with a tank that supply the water through a triangle sharp-crested weir, placed at the entrance of the flume and used to measure the flow rate. The flow rate was regulated by using a valve connected with a delivery pipe and adjusted by the corresponding head over the weir. The flow depth was controlled (under free flow conditions) with an adjustable tail sill as shown in plate(1).

Plate (1) General view of the laboratory flume with one of the piers.

The bed of the flume was filled and uniformed with sand (d_{50}=0.56 mm) to a depth of 10 cm, the uniformity coefficient was (2.3) . The grain size distribution of sand was presented in Fig. (1). Four models of a rectangular section semicircular nose piers were manufactured from thermo-stone and painted to decrease the surface roughness of these piers, the upstream semicircle width was fixed with a diameter of 12 cm, while the downstream diameter was changed as follows (d_2= 10,8,6 and 4 cm). In each test, every pier was fixed in the middle of the test section in the flume, while for each run the sand surface around the pier was leveled carefully .The discharge in the flume was gradually increased to prevent any disturbance in the bed material until the desired discharge was achieved, the flow rate were changed three times, 5,8 and 12 L/s. Each test was run until the equilibrium stage of scour was reached. After the run was stopped the maximum equilibrium scour depth and other scour depths around the pier were measured carefully by a point gauge with an accuracy of ± 0.1 mm.

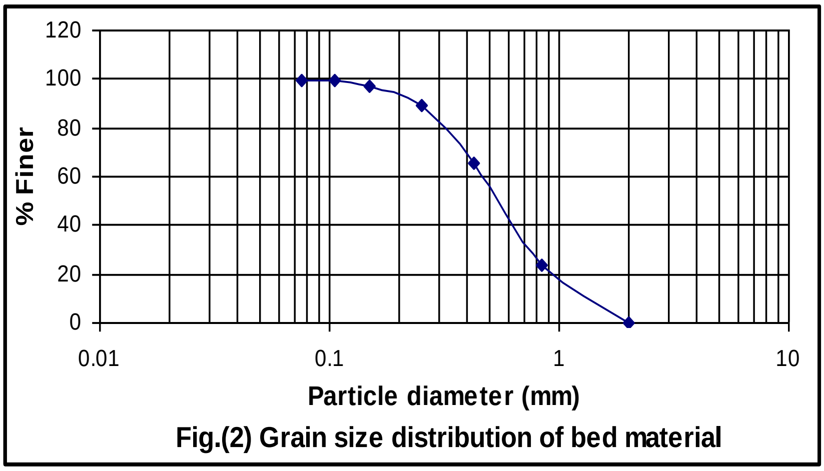

Fig.(1) Grain size distribution of bed material.

Artificial Neural Networks (ANN)

1. Facility of artificial neural networks

The neural network techniques could be adopted for the purpose of comparison and classification. Applications using such nets can be found virtually in every field that uses neural nets for problems that involve mapping a given set of inputs to a specified set of target outputs. As is the case with most neural networks, the aim is to train the net to achieve a balance between the ability to respond correctly to the input patterns that are used for training (memorization) and the ability to give reasonable (good) responses to input that is similar, but not identical, to that used in training (generalization).

2. Back propagation neural network

Properly trained back propagation networks tend to give reasonable answers when presented with inputs that they have never seen. Typically, a new input leads to an output similar to the correct output for input vectors used in training that are similar to the new input being presented. This generalization property makes it possible to train a network on a representative set of input/target pairs and get good results without training the network on all possible input/output pairs[11]. The training of a network by back propagation involves three stages: the feed forward of the input training pattern, the calculation and back propagation of the associated error, and the adjust of the feed forward phase. Even if training is slow, a trained net can produce its output very rapidly. Numerous variations of back propagation have been developed to improve the speed of the training process. Although a single-layer net is severely limited in the mappings it can learn, a multilayer net (with one or more hidden layers) can learn many continuous mapping to an arbitrary accuracy. More than one hidden layer may be beneficial for some applications, but one hidden layer is sufficient[12].

3. Architecture of standard back propagation

A multilayer neural network with one layer of hidden units (the Z units) is shown in Fig. (2). The output units (the Y units) and the hidden units also may have biases (as shown). The bias on a typical output unit Y_k is denoted by w_{0k}; the bias on a typical hidden unit Z_j is denoted v_{0j}. these bias terms act like weights on connections from units whose output is always 1. Only the direction of information flow for the feed forward phase of operation is shown. During the back propagation phase of learning, signals are sent in the reverse direction[12].

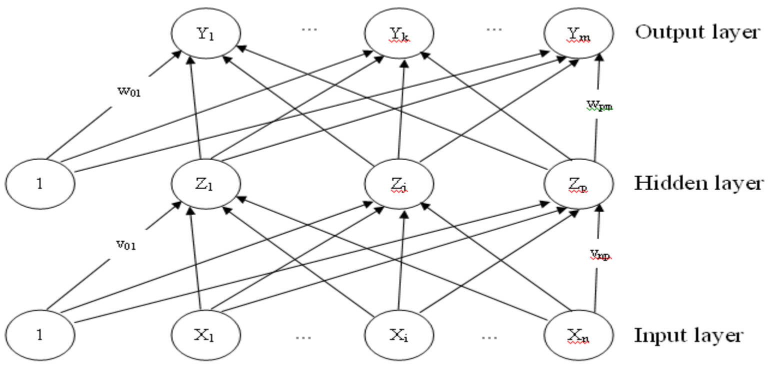

Figure (2): Back propagation neural network with one hidden layer.

4. Training algorithm for back propagation neural network

The general training algorithm for one hidden layer back propagation neural network, which is adequate for a large number of applications, is as follows:

Step 0. Initialize weights.
(Set to small random values).
Step 1. While stopping condition is false. do Steps 2-9.
Step 2. For each training pair. do Steps 3-8.

Feed forward:
Step 3. Each input unit (x_i, i = 1……n) receives input signal x_i and transports this signal to all units in the layer above (the hidden units).
Step 4. Each hidden unit (z_j, j = 1………p) sums its weighted input signals.

$$z\_in_j = v_{0j} + \sum_{i+1}^{n} x_i v_{ij} \qquad \text{……………………………………………….. (7)}$$

Where v_{0j},v_{ij} is the bias and weights on a typical hidden units, x_i is the input signal and z_in_j is the input net of hidden layer. Then applies its activation function to compute its output signal.

$z_j = f(z\_in_j)$.

and sends this signal to all units in the layer above (output units).
Step 5. Each output unit (y_k, k = 1 ……… m) sums its weighted input signals.

$$y\_in_k = w_{0k} + \sum_{j=1}^{p} z_j w_{jk} \qquad \text{…..…..………………………………….. (8)}$$

Where w_{0j}, w_{ij} is the bias and weights on a typical output units, z_i is the hidden signal and y_in_j is the input nets of output layer. Then applies its activation function to compute its output signal.

$$y_k = f(y\_in_k).$$

Back propagation of error:

Step 6. Each output unit (Y_k, k = 1……..m): receives a target pattern corresponding to the input training pattern, computer its error information term.

$$\delta_k = (t_k - y_k)\, f'(y\_in_k) \quad \text{.. (9)}$$

Where t_k is the desired target and δ_k is the error on output layer.
So, to calculate its weight correction term (used to update w_{jk} later).

$$\Delta w_{jk} = \alpha \delta_k z_j \quad \text{.. (10)}$$

Where α is the learning rate.
So, to calculates its bias correction term (used to update w_{0k} later).

$$\Delta w_{0k} = \alpha \delta_k \quad \text{.. (11)}$$

And sends δ_k to units in the layer below.

Step 7. Each hidden unit (Z_j, j = 1………p) sums its delta inputs (from units in the layer above).

$$\delta\_in_j = w_{0k} + \sum_{k+1}^{m} \delta_k w_{jk} \quad \text{.. (12)}$$

Where δ_in_j is the error inputs on hidden layer. This error inputs multiplies by the derivative of its activation function to calculate its error information term.

$$\delta_j = \delta\_in_j\, f'(z\_in_j) \quad \text{.. (13)}$$

Where δ_j is the error on hidden layer.
Calculates its weight correction term (used to update v_{ij} later)..

$$\Delta v_{ij} = \alpha \delta_j x_i \quad \text{...................................... (14)}$$

And calculates its bias correction term (used to update v_{0j} later).

$$\Delta v_{0j} = \alpha \delta_j \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (15)$$

Update weights and biases:

Step 8. Each output unit (Y_k, k = 1…….m) updates its bias and weights (j = 0……..p):

$$w_{jk}(new) = w_{jk}(old) + \Delta w_{jk} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (16)$$

Each hidden unit (Z_j, j = 1……..p) updates its bias and weights (i = 0……n):

$$v_{ij}(new) = v_{ij}(old) + \Delta v_{ij} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (17)$$

Step 9. Test stopping condition. [12].

5. Suggested topology

The Back propagation network which is suggested has five nodes in the input layer, three nodes in the hidden layer and one node in the output layer 5-3-1 . The activation functions used are tan-sigmoid activation functions in the hidden layer and pure-linear activation function in the output layer.

Results and discussions

The variation between ds/d_1 with d_2/d_1 for different discharges has been shown in Fig.(3) . It appeared evidently that the depth of scour D/S the pier increases with increasing of d_2/d_1.Further more , the increase in water discharge contribute to increase the scour depth . So, it could be well considered that the decrease in the D/S diameter d_2 of the pier guides to decrease the scour depth. This leads to increase the stability of the bridge pier and decrease the risk of the pier failure.

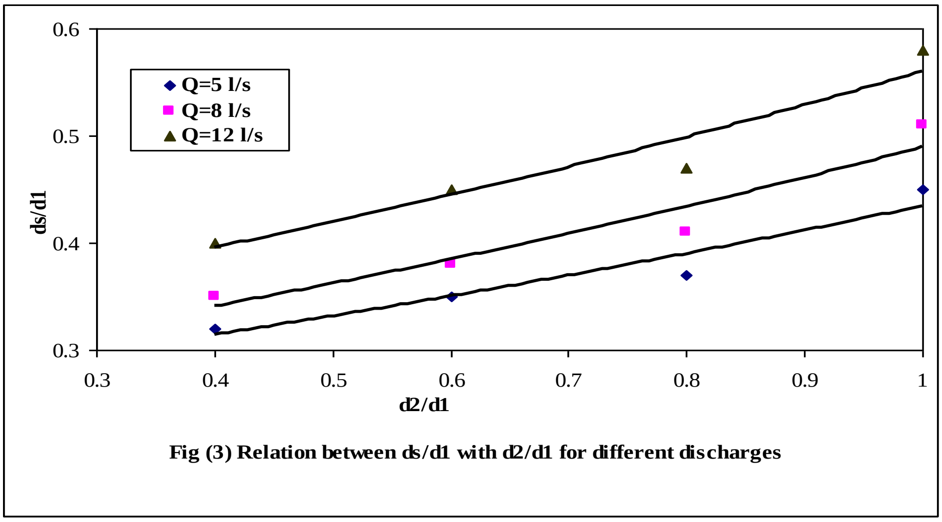

Fig (3) Relation between ds/d1 with d2/d1 for different discharges

The influence of d_2/d_1 on y/d_2 for different discharges was exposed in Fig.(4). It is observed from this figure that instead of the local scour D/S the pier the sand was deposited appreciably when the D/S diameter of the pier was reduced . This deposition was happened because the velocity of water flow was decreased and contribute to accumulate the sand D/S the pier . The minimum value of y/d_2 was obtained when d_2/d_1 equal one . This point gives the maximum depth of scour as shown previously in Fig.(3). The deposition of sand was increased about 75% ,72% and 67% when the discharges 12, 8 and 5 L/s respectively with the decreasing in the D/S diameter. That means the elimination of scour D/S the pier could be take place when this type of piers will be used mainly when d_2/d_1= 0.4. So, this diameter could be suggested for the design of bridge piers.

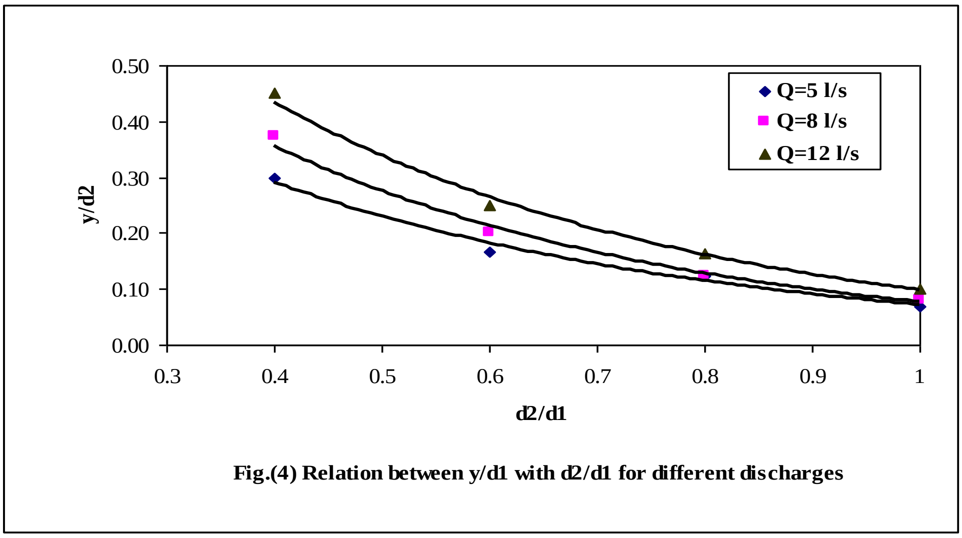

Fig (4) Relation between Y/d1 with d2/d1 for different discharges

In Fig.(5) the relation between X/d_1 with d_2/d_1 was plotted which shows the length of scour arrives at the highest when d_2/d_1 equal one. The decrease in the length when d2/d1 equal 0.4 is about 13% in comparison with d2/d1 equal one when the discharge 12 L/s . Further more, X/d_1 become evident higher by 21% at the discharge 12 L/s for all types of piers .

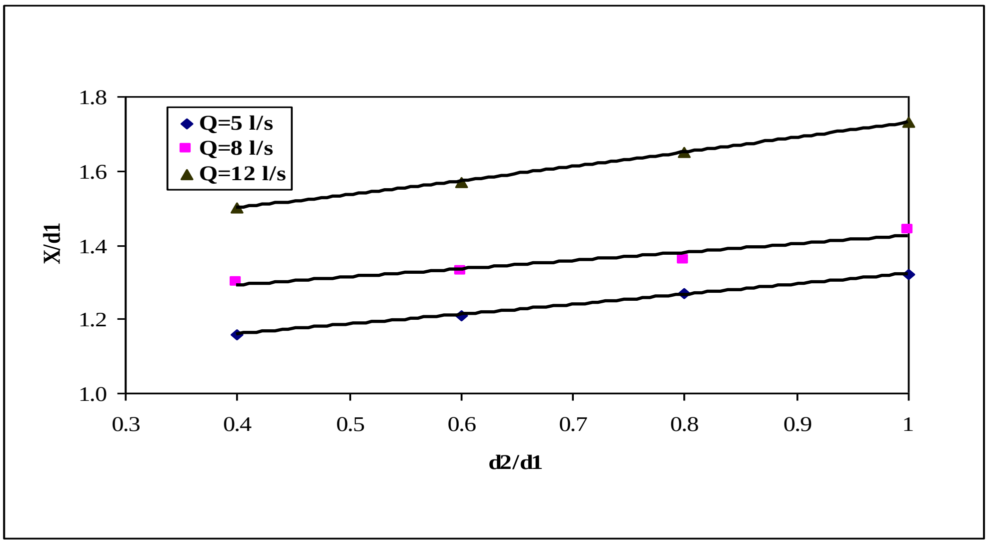

Fig (5) Relation between X/d1 with d2/d1 for different discharges

In order to build up a general equations for both maximum depth and length of scour D/S the piers based on equations (5) and (6). A number of trials are attempted to employ the multiple regression analysis techniques. The experimental data are utilized to build the finest two linear models :

$$ds/d_1 = 0.37\, d_2/d_1 + 0.48\, Z_1/d_2 - 0.4\, Z_2/d_2 - 0.15\, y/d_2 + 1.94\, Fr \qquad \text{-------- (18)}$$

$$X/d_1 = 1.33 - 0.4 d_2/d_1 + 3.3\, Z_1/d_2 - 2.2\, Z_2/d_2 + 2.3\, y/d_2 - 3.7\, Fr \qquad \text{------ (19)}$$

Equations (18) and (19) with a correlation coefficients of (0.96) and (0.97) respectively .The computed values of these equations will be used for comparison with ANN values latterly .

The back propagation network topology, as shown in Fig. 6, is a multiple-layer consisting of 5 nodes for input, 3 nodes for hidden and 1 node for output. It has 22 weights and biases to be stored in the database file. The data input stream is parallel for each input vector.

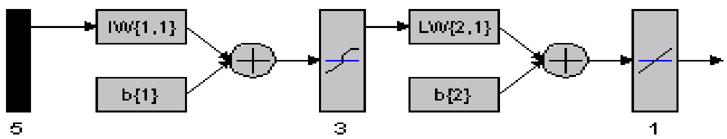

Fig. 6: Back propagation network architecture

Fig. 7 shows the back propagation training curve for ds/d1 which proved that the train was reached to its successive values (less error). Also, Fig.(8) shows the comparison between the measured ds/d1 with the results of the ANN and the regression equation (18) .The figure shows obviously that the use of ANN gives an excellent identical with the measured ds/d1 by correlation coefficient 0.98 . While it is greatly superior than the employ of equation (18) with correlation coefficient 0.92 . This represents that the utilize of ANN techniques for predicting is much better than the regression techniques .

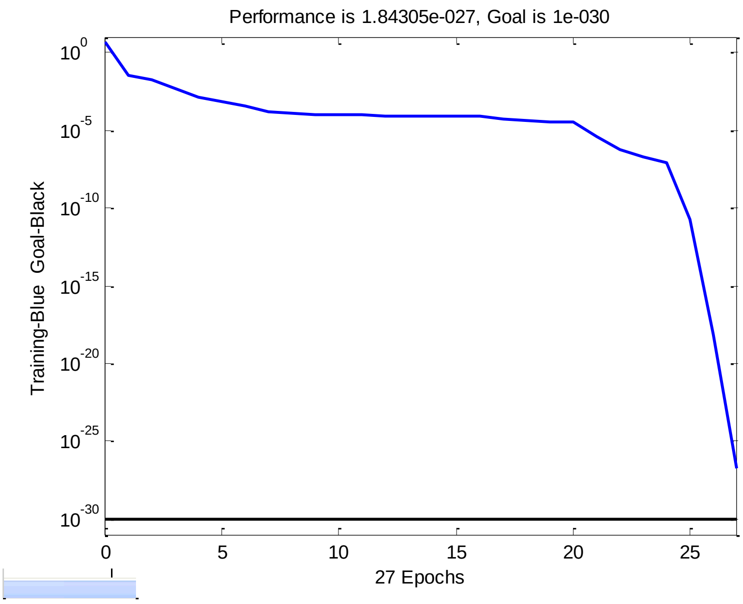

Fig. 7 : Back propagation training curve for ds/d1

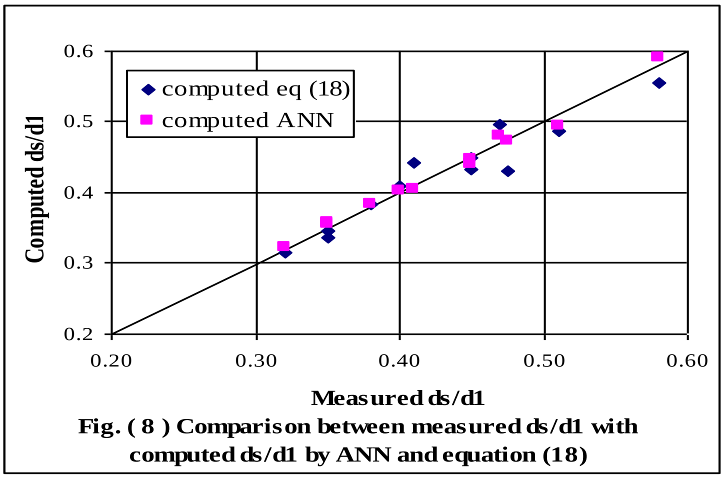

Fig (8) Comparison between measured ds/d1 with computed ds/d1by ANN and equation (18)

Fig. 9 shows the back propagation training curve for X /d1 which proved that the train was reached to its successive values (less error). Also, Fig.(10) illustrates the comparison between the measured X/d1 with the results of the ANN and the regression equation (19) . The figure explains that the use of ANN provides an excellent identical with the measured X/d1 by correlation coefficient 0.96 . While it is much better than the employ of equation (19), with correlation coefficient 0.93 , to predict the length of the scour.

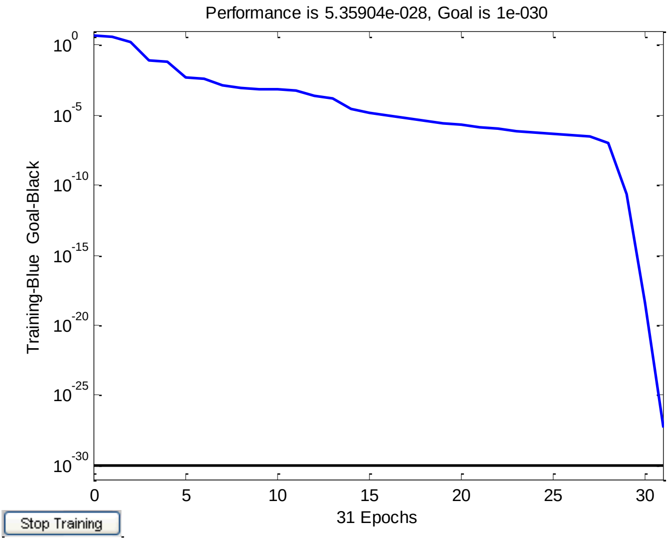

Fig. 9 : Back propagation training curve for X/d1

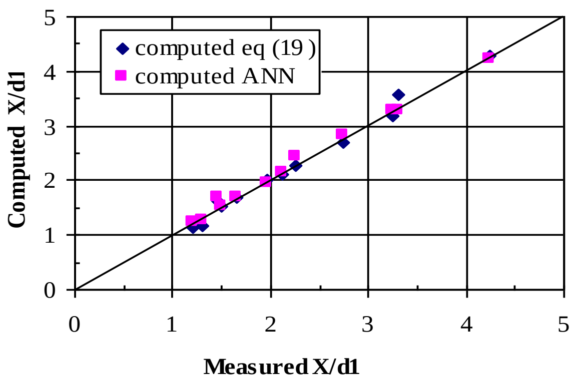

Fig. (10) Comparison between measured X/d1 with computed X/d1 by ANN and equation (19)

Fig (10) Comparison between measured X/d1 with Computed X/d1by ANN and equation (19)

Conclusions

The results of this study shows that the reducing of the D/S diameter of the pier leads to decrease the D/S scour depth and length. And instead of that the sand was appreciably accumulated D/S the pier. This finding encourages to use these bridge piers in water resources projects. The suitability of ANN techniques were examined also in modeling the depth and length of scour D/S these piers and compared with the regression techniques. The utilize of ANN techniques yields better results as compared to liner empirical equations for predicting the depth and length of scour D/S these piers .

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