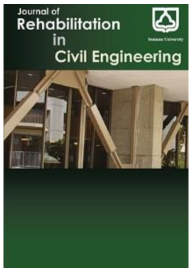
Journal of Rehabilitation in Civil Engineering 3-2 (2015) 59-66



Journal homepage: http://civiljournal.semnan.ac.ir/

Estimating of Scour in Downstream of the Water Level Regulation Structures

S. Farzin[1*], M. H. Ahmadi[2], R. Rajabpour[2], F. Alizadeh Sanami[3], K. Asaii[2]

1. Assistant Professor, Faculty of Civil Engineering, Semnan University, Semnan, Iran.
2. Young Researchers and Elite Club, Beyza Branch, Islamic Azad University, Beyza, Iran.
3. Ph.D. Student, Faculty of Civil Engineering, Iran University of Science and Technology, Tehran, Iran.
* Corresponding author: saeed.farzin@semnan.ac.ir

ARTICLE INFO

Article history:
Received: 31 August 2015
Accepted: 15 June 2016

Keywords:
Scour estimation,
Water level regulation,
Error back propagation,
Artificial neural networks.

ABSTRACT

Scour in the downstream of hydraulic structures is a phenomenon which usually occurs due to exceeding the velocity or shear stress from a critical level. In this paper by using the laboratory data by Borman- Jouline and De-Agostino research, it was tried to get more accurate equations in order to calculate the maximum depth of scour in the downstream of the water level regulation structures. Comparing these equations with the results of the other researchers showed that these equations are much more accurate. After that Artificial neural networks (ANNs) with learning algorithm of error back propagation (BP) were used to estimate maximum water scour depth, and the model which has seven neurons in its hidden layer was produced as the most appropriate model. Finally by using statistical parameters, the ANN model was compared with optimized equations. The results of this study showed high correlation between artificial neural network and proposed equation.

1. Introduction

Scourin the downstream of hydraulic structures is a phenomenon which usually occurs due to inordinate local velocity or more shear stress than allowable stress. The main reasons of this phenomenon can be stated as follows:

a) Insufficient value of energy depreciation

b) Formation of impermanent hydraulic jumpor transmission the jumpout of the stilling basin.

c) Create eddy streams in downstream of hydraulic structures.

Determination of water scourdepth is very important because it can damage the structure. Considering of many researches, it is specified that scourdepth in the downstream of structure depends on the structures geometrical characteristics in addition to sediment and flow hydraulic. Because the flow behavior is three dimensional near hydraulic structures, the performance of computer models is limited in these cases. Since multiple parameters are included in the scale of scourdepth and also surveying and studying of the effect of all of these parameters is not possible, so usually the examinations will be done when a number of parameters are constant. So even for a specific structure, usually multiple relations are created during years that unfortunately, their results can be very different from each other.

In this research, level regulatorsare considered. Downstream scourof these structures which is created in alluvial riverbed, is a complex and three dimensional phenomenon. So we investigate the empirical formulas.

Rouse [1] and Doddiah [2] showed that scourdepth increases during years with following equation:

$$\frac{s}{h} = k_1 + k_2 \log\left(\frac{QT}{bz^2}\right) \tag{1}$$

In this relation, *s* is scourdepth (m), k_1 and k_2 are constant coefficients, *h* is the shoal depth toward the non-erosion bed height in overflow upstream (m), Q is discharge (m3/s), *T* is time (s), *b* is spillwaywidth (the width of level regulator structure, (m)) and *z* is the height of head of water over the weir from the non-erosion bed in overflow downstream (m). The abovementioned parameters are shown in figure (1).

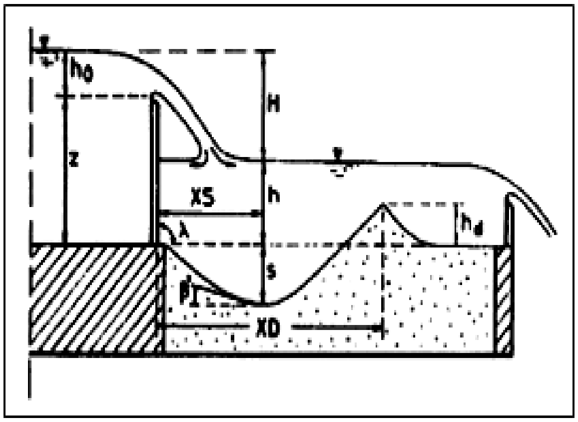


Fig 1. scour in the downstream of height regulator structure

In order to determine the distance between structures downstream (XD), De Agostino[3] presented the following Equation regardless the effect of ingredients’ size.

$$\frac{XD}{z} = \frac{3.55}{z}\sqrt[3]{\frac{q^2}{g}} + 0.34 \tag{2}$$

In the Equation (2), q is discharge in width scale of overflow (m3/s) and g is acceleration of gravity (m/s2).

Schoklitsch [4] did a number of examinations on those gradients with widespread attaching distribution. He observed that in both cases, paving phenomenon of intake bed had happened. He introduced d_{90} (mm) as the width of ingredients for estimating the maximum scour depth in downstream of fall and presented the relation (3)

$$s = 4.75\frac{H^{0.2}q^{0.5}}{d_{90}^{0.3}} - d_2 \tag{3}$$

Where d_2 is the downstream depth (m) and H is the height differentiation between structure upstream and downstream(m) (figure 1).

Bormann and Jolene [5] by examining on models with large scales under the condition of vertical jets, wall jets, free falling jets and absorb jets, presented the equation (4) in order to calculate the maximum scour depth.

$$s=\left[\frac{0.611}{\left[\sin\left(0.436+\beta'\right)\right]^{0.8}}q^{0.6}\frac{U_0}{g^{0.8}d_{90}^{0.4}}\sin\beta'\right]-z \qquad (4)$$

Where, U_0 is the average velocity in head of water over the weir (which is considered equal to the speed of jet entrance to downstream water, (m/s)) and β’ is the maximum angle between upstream mode of scourwhole and horizontal line to radian.β’ angle is almost equal to jet entrance angle, and is calculated through equation (5).

$$\beta'=0.316\sin\lambda+0.15\mathrm{Ln}\left(\frac{z+Y_0}{Y_0}\right)+0.13\mathrm{Ln}\left(\frac{h}{Y_0}\right)-0.05\mathrm{Ln}\left(\frac{U_0}{\sqrt{gY_0}}\right) \qquad (5)$$

Where, λ is downstream angle of water regulator structure with horizontal line in radian and Y_0 is the water depth in head of water over the weirin meter.

Masonand Arumugam[6] by examining several equations in order to estimating maximum scourdepth understood that the best introducer of grain size distribution is the ingredient’s mean size (d_s, mm). They presented the following formula.

$$s=\left(6.42-3.1H^{0.1}\right)g^{-\frac{H}{600}}\times\left(\frac{gH^3}{q^2}\right)^{20+\frac{H}{600}}\left(\frac{H}{d_s}\right)^{1/10}\left(\frac{h}{H}\right)^{3/20}\times\left(\frac{q^2}{g}\right)^{1/3} \qquad (6)$$

De Agostino and Ferro [7] by using their own method dimensional similarity and also a number of laboratory data which were gathered from different sources, present relations for calculating Scour depth.

$$s=0.975\left(\frac{h_0}{z}\right)^{0.863}z \qquad (7)$$

$$s=0.54\left(\frac{b}{z}\right)^{0.593}\left(\frac{h}{H}\right)^{-0.126}\left(A_{50}\right)^{0.544}\left(\frac{d_{90}}{d_{50}}\right)^{-0.856}\left(\frac{b}{B}\right)^{-0.751}z \qquad (8)$$

There are so many researches on determining scour depth. A few important works and their proposed relations are showed in table 1.

Table1. relations proposed by different researchers

Jarger[8]	$s+D_p=0.6q^{0.5}H^{0.25}Y_t^{0.33}/d_s^{0.4}$	scale of scour depth
Hartoung[9]	$s+D_p=1.4q^{0.64}H^{0.36}/d_s^{0.32}$	Estimate the maximum range of scour.
Heeand Padiyar[10]	$s+D_p=2.1q^{0.67}H^{0.18}/d_s^{0.06}$	calculate the maximum scour depth in Philip bucket
Cheeand Kung [11]	$s+D_p=1.7q^{0.6}H^{0.2}/d_s^{0.1}$	estimate the maximum scour depth in stilling basin
Martins [12]	$s+D_p=1.5q^{0.6}H^{0.1}$	for rivers with stone bed
Chee and Youen[13]	$s+D_p=0.6q^{0.45}U_0^{0.55}\beta^{0.1}/d_s^{0.1}$	for rivers with sandy bed

2. MATERIALS and METHODS

2.1.Thedownstreamflow characteristics of height regulator structures’

The range of scour in these structures depends on following matters:

2.1.1. jet kind

In this relation, scour can be divided into two classes, scour under free jet and scour under absorbed jet.

2.1.2. Jet distribution in Downstream

Analysis of free jet data by Youen [14] shows that jet distribution angle in downstream is equal to jet contact angle with free surface. Also Berman and Jouline[5] believe that jet distribution angle depends on following parameters:

$$\beta' = f\left(\frac{D_p + Y_0}{Y_0}, \frac{U_0^2}{gY_0}, \frac{Y_0}{Y_t}, \sin\lambda\right) \tag{9}$$

The studies of Akashi and Saito [15], Rajaratnam[16] and Youen[14] showed that downstream slope angle almost is equal to upstream slope angle (β').

2.1.3. the stability of bed materials in scour hole

Shear stress in scour hole can be calculated by:

$$\tau_f = C_f \rho U_b^2 \tag{10}$$

Where τ_f (N/m2) and ρ (Kg/m3) are Shear stress in bed and water density (Kg/m3). Also U_b(m/s) and C_f are the velocity in scour hole and local friction coefficient which are gained through the relations 29, 30 and 31 respectively.

$$U_b = C_d . U_0 \cdot \left(\frac{Y_0}{L_s}\right)^{0.5} \tag{11}$$

$$L_s \geq C_d{}^2 Y_0 \tag{12}$$

Jet diffusion coefficient depends on the condition of entering jet but it is almost free from jet angle. Albertson [17], Beltous and Rajaratnam [18] and Yenh [19] proposed C_d value between 2 to 2.4 for wall jets.

$$C_f = \frac{\theta_{cr}}{a}\left(\frac{d_s}{Y_b}\right)^b \tag{13}$$

Where, a and b can be obtained by table (2). θ_{cr} is also the Shields critical shear stress which is equal to 0.047 or 0.056 for turbulent heavy and completely developed flow and for developing boundary layer is equal to 0.11. Also in relation (31), Y_b is the diffused jet diameter and can be calculated through relation (32).

$$Y_b = \frac{U_0}{U_b} Y_0 \tag{14}$$

Table2. Proposed values for a and b

researcher	a	b
Uoqadi-a [14]	0.001	1.2
Uoqadi-b [14]	2.9	0.19
Neill [20]	2	0.33

3. Dimensional analysis and effective parameters

Several parameters are effective on maximum scour depth; these parameters can be divided into two general groups:

a) The parameters which are related to structure and flow characteristics;Which involve the canal width (B, m), level regulator structure width (b, m), flowdischarge (Q, m3/s) water density(ρ, kg/m3), downstream depth to non-erosion bed height in weirupstream (h, m), height difference between upstream and structure downstream (H, m), difference of spillway crest from non-erosion bed in weirdownstream (z, m) and gravitational acceleration (g, m/s^2).

b) The parameters which are related to sediment characteristics;this classification includes grain's size (d_{50} and d_{90}, mm), density of erosion bed materials (ρ_s, kg/m^3), and their grading distribution (their uniformity or un-uniformity).

Both parameters can be summarized in the form of relation (33):

$$s = \Phi(z, b, B, h, H, Q, \rho_S, \rho, g, d_{50}, d_{90}) \tag{15}$$

By using the Buckingham dimensional analysis and dimensionless groups' mixture, the following functions will be gained:

$$\frac{z}{s} = f\left(\frac{H}{h}, A'_{50}, \frac{d_{90}}{d_{50}}, \frac{b}{B}\right) \tag{16}$$

$$\frac{z}{h} = f\left(\frac{d_{50}}{h}, \frac{H}{h}, A'_{50}, \frac{d_{90}}{d_{50}}, \frac{b}{B}\right) \tag{17}$$

And A'_{50} will be gained through following relation.

$$A'_{50} = \frac{Q}{bh_0\left(gd_{50}\left(\frac{\rho_s - \rho}{\rho}\right)\right)^{0.5}} \tag{18}$$

4. Artificial neural networks

In fact artificial neural networks (ANNs) are inspired from the human brain. These networks try to model brain neuron structure and are able to do operations which are almost similar to biologic neurotic systems. The ability to learn and also correct local errors during processing input are of artificial neural networks characteristics. These characteristics can be used in cases such as pattern isolation, robotics, control and generally where it is needed to learn a linear and nonlinear mapping [21].

The first works on artificial neural networks were done by Mac Cloth and Pitters in 1943. Frank Rouzenblot also in 1958 described perceptron network. Hapelfild in 1958 by describing reversal networks and David Ramelhart and Jims Macland changed neural networks by presenting error back propagation (BP) training algorithm [22].

In each neuron, according to relation (37) input vector x(j) is multiplied in a cycle of weight coefficients (w(i,j) and is added to a bias b(i)).

$$n(i) = \sum_{j=1}^{J} w(i, j)x(j) + b(i) \tag{19}$$

5. Discussion

By using Bormann – Jolene and De Agostino experimental data for a condition in which bed materials are not uniform graded, following equation (1) with correlation coefficient of 0.7 is the best relation:

$$s = 46.345\left(A'_{50}\right)^{0.457}\left(\frac{d_{50}}{h}\right)^{0.302}\left(\frac{d_{90}}{d_{50}}\right)^{-4.317}\left(\frac{H}{h}\right)^{0.1535}\left(\frac{b}{B}\right)^{6.787} \tag{20}$$

From the total 135 data, 124 data were chosen for calibration and 11 data which was selected randomly, was used for correction.Also by using 114 data of De Agostino [3, 7] equation was corrected as follows for finding the best estimation. Relation (40) is very accurate by correlation coefficient of 0.845 (figures 2, 3, 4, 5).

$$s = 0.43404\left(\frac{b}{z}\right)^{0.49468}\left(\frac{h}{H}\right)^{0.13336}\left(A'_{50}\right)^{0.50215}\left(\frac{d_{90}}{d_{50}}\right)^{0.20682}\left(\frac{b}{B}\right)^{0.26192} \tag{21}$$

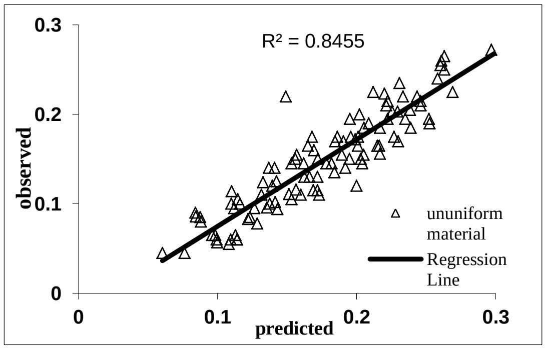


Fig 2. Comparison of s values by equation (21) with experimental data (ununiformed graded)

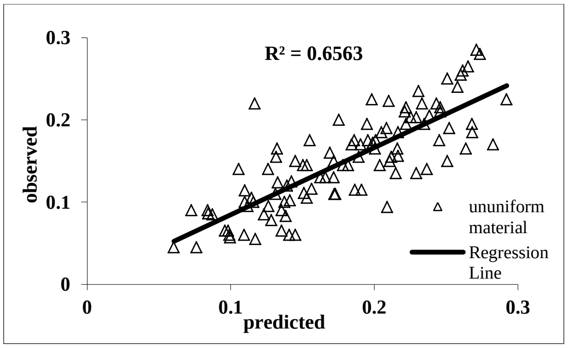


Fig 3. Comparison of s by equation (8) with experimental data (ununiformed graded)

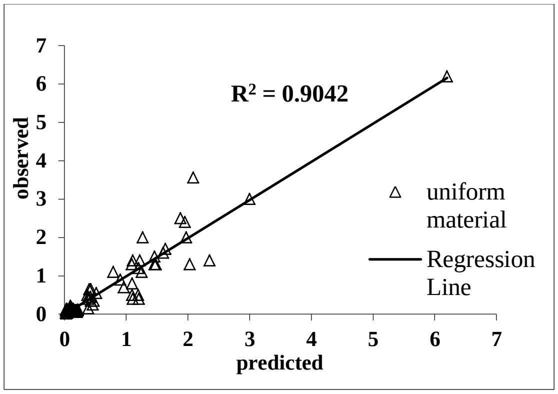


Fig 4. Comparison of s by equation (21) with experimental data (uniformed graded)

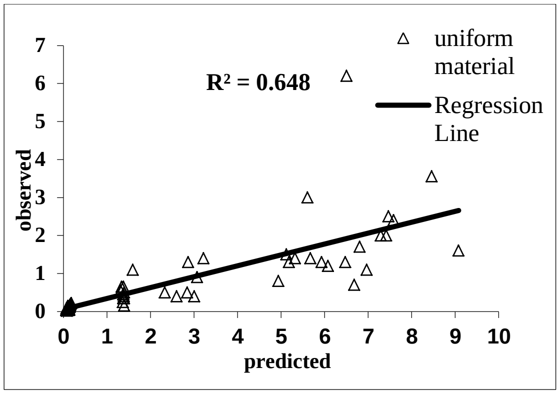


Fig 5. Comparison of s values by equation (8) with experimental data (uniformed graded)

As it was mentioned, in addition to optimized equations, artificial neural networkis used to calculate maximum scour depth. So in this research MLP networks by error back propagation (BP) training algorithm were used.So about 70% of data was assigned to network training and the rest of them were usedfor network test.

There is just one neuron in output layer and this neuron output is the value of $\left(\frac{z}{s}\right)$.

By using trial and error, several structures were modeled and the results of these models are shown in tables3 and 4.

Table 3. the results of neural network in training stage

model	MAD	Std	MAE	MSE	R^2	neurons in hidden layer
1	0.486	0.789	0.489	0.623	0.926	5
2	0.412	0.672	0.422	0.522	0.942	6
3	0.377	0.621	0.378	0.385	0.954	7
4	0.383	0.630	0.385	0.292	0.952	8
5	0.393	0.639	0.395	0.408	0.951	9
6	0.466	0.752	0.467	0.565	0.923	10
7	0.802	1.217	0.726	1.559	0.920	12
8	0.952	1.222	0.854	1.627	0.892	15

Table4. the results of neurotic network in test stage

Model	MAD	Std	MAE	MSE	R^2	neurons in hidden layer
1	0.474	0.692	0.485	0.483	0.934	5
2	0.422	0.639	0.428	0.430	0.938	6
3	0.382	0.586	0.386	0.348	0.953	7
4	0.503	0.724	0.510	0.685	0.912	8
5	0.538	0.820	0.541	0.705	0.905	9
6	0.550	0.842	0.549	0.712	0.903	10
7	0.581	0.861	0.594	0.747	0.898	12
8	0.657	0.922	0.672	0.789	0.882	15

Table 5. usable statistical

Mean Absolute Deviation(*MAD*)	$MAD = \sum_{i=1}^{n} \lvert e_i - \bar{e} \rvert \Big/ n$
Standard Deviation (*Std*)	$Std = \sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2 \Big/ n}$
Mean Absolute Error (*MAE*)	$MAE = \sum_{i=1}^{n} \lvert t_i - a_i \rvert \Big/ n$
Mean Square Error (*MSE*)	$MSE = \sum_{i=1}^{n} (t_i - a_i)^2 \Big/ n$
Correlation Coefficient(R^2)	$R^2 = 1 - \sum_{i=1}^{n} (t_i - a_i)^2 \Big/ \sum_{i=1}^{n} (t_i - \bar{t})^2$

Where t_i is i^{th} desired output and $\bar{t}$ is the mean of desired outputs, a_i is i^{th} output of artificial neural network, i^{th} output of optimized equation, ei is i^{th} error and $\bar{e}$ is error mean value. For calculating the error value, following relation is used.

$$e_i = (t_i - a_i) \tag{22}$$

As you see, by considering statistical standard, the structure number 3 with seven neurons in hidden layer is the best and most proper model of artificial neural network for calculating the value of $\left(\frac{z}{s}\right)$.

Figures (9 and 10) show the result of neural model performance in two stages of test and training.

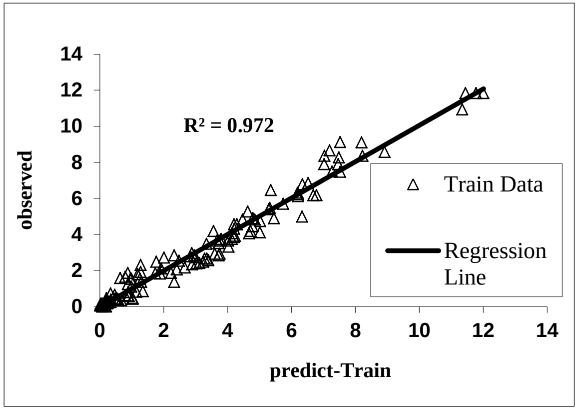


Fig 6. Comparison of (z/s) values which were gained through network training phase with real values

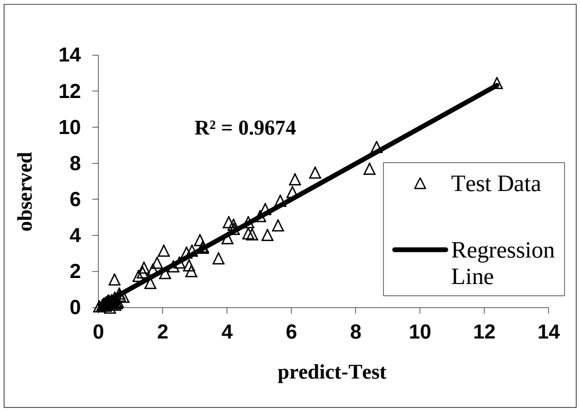


Fig 7. Comparison of (z/s) values which were gained through network test phase with real values

6.CONCLUSIONS

In this paper in addition to a review about downstream scour of height regulating structures by using the data which were gained by the previous studies (De Agostino and Bormann – Jolene) and by separating bed classification to two groups of uniform and non- uniform, some relations were presented which can be used for prospecting the maximum depth of downstream scour of height regulating structures. This work has been done because, it was imagined that bed larger ingredients by non-uniform propagation resulted in decreasing of scour. Also the accuracy of presented relations with the last relation which was presented by De Agostino [14] was compared for prospection of maximum scour depth for height regulator structures. The results showed that new relation is a better estimation than the relation which was presented by De Agostino.Also artificial neural network was used by error back propagation training algorithm for estimating scour depth (s) and the model which has seven neurons in its hidden layer was gained as the best structure.The results which were gained from this model, have a well accordance with laboratory data and are more accurate than specified relations. So the use of artificial network is very suitable for scour estimation.

REFERENCES

[1] Rouse, H. (1940).“Criteria for similarity in the transportation of sediment.Studies in engineering bull”., Univ. of Iowa, 20, 33–49.

[2] Doddiah, D., Albertson, M. L., and Thomas, R. (1953). “Scour from jets”. Proc., 5th Congr. Int. Assoc. for Hydraulic Res., Minneapolis, September, 161–169.

[3] D'Agostino, V. (1996). "La progett azionedell econtro briglie. Proc., 25th Convegno di Idraulica e Costruzion iIdrauliche", Torino, September, 3, 107–118 (in Italian).

[4] Schoklitsch, A. (1932). "Kolk bildun gunter Ueberfall strahlen". Wasser wirtschaft, 24, 341–343 (in German).

[5] Bormann, N. E., and Julien, P. Y. (1991). "Scour downstream of gradecontrol structures". J. Hydraul. Eng., 117(5), 579–594.

[6] Mason, P. J., and Arumugam, K. (1985). "Free jet scour below dams and flip buckets". J. Hydraul. Eng., 111(2), 220–235.

[7] D'Agostino, V., and Ferro, V. (2004). "Scour on Alluvial Bed Downstream of Grade-Control Structures. J. Hydraul. Eng., 130(1), 24–37.

[8] Jager, C. (1939). "Uber die AehnlichkeitbeiflussaulichenModellversu chen. Wasserkraft und Wasserwirtschaft.34(23/24), 269, (in German).

[9] Hartung, W. (1959). "Die Kolkbildung hinter U berstro¨mtenWeherenimHinblick auf eineBeweglichSturzbettgestaltung. Wasserwirtschaft, 49(1), 309–313 (in German).

[10] Chee, S. P., and Padiyar, P. V. (1969). "Erosion at the base of flip buckets". Eng. J., 52(111), 22–44.

[11] Chee, S. P., and Kung, T. (1974). "Piletas de derrubioautoformadas". Proc., 6th Congr. Int. Assoc. for Hydraulic Res., Bogota, Columbia, Paper No. D.7, 1–11.

[12] Martins, R. (1975). "Scouring of rocky riverbeds and free-jet spillways". Int. Water Power Dam Constr., 27(5), 152-153.

[13] Chee, S. P., and Yuen, E. M. (1985). "Erosion of unconsolidated gravel beds". Can. J. Civ. Engrg., 12, 559-566.

[14] Yuen, E. M. (1984). "Clearwater scour by high velocity jets".Thesis presented to the University of Windsor, at Windsor, Ontario, in partial fulfillment of the requirements for the degree of Master of Science.

[15] Akashi, N., and Saitou, T. (1986). ''Influence of water surface on scour from vertical submerged jets.'' J. Hydrosci. Hydr.Engrg., 55-69.

[16] Rajaratnam, N. (1981). "Erosion by plan turbulent jets". J. Hydraul. Res., 19(4), 339–358.

[17] Albertson, M. L., Dai, Y. B., Jensen, R. A., and Rouse, H. (1950). ''Diffusion of submerged jets". Trans., ASCE, 115(2409), 639-697.

[18] Beltaos, S., and Rajaratnam, N. (1973). "Plane turbulent impinging jets". J. Hydr. Res., 11(1), 29-59.

[19] Yuen, E. M. (1984). "Clearwater scour by high velocity jets". Thesis presented to the University of Windsor, at Windsor, Ontario, in partial fulfillment of the requirements for the degree of Master of Science.

[20] Neill, C. R. (1968). "Note on initial movement of coarse uniform bed material". J. Hydr. Res., 6(2), 173-176.

[21] Patterson, D. (1996). "Artificial Neural Networks: Theory and Applications. Singapore: Prentice Hall.

[22] Alborzi, M. (2000). "Introduction to Artificial Neural Networks". Institute of Scientific Publications.