APPLICATION OF ARTIFICIAL NEURAL NETWORK IN OCCURRENCE OF BREAKING WAVES

Hasan Ibrahim Al Shaikhli* , Prof. Dr. Saleh Issa Khassaf
Civil Engineering Department, College of Engineering, University of Basrah, Basrah, Iraq.
E.hassanibraham@gmail.com, Saleh.Khassaf@uobasrah.edu.iq

Abstract

This study seeks to explore all characteristics that influence the occurrence of breaking waves, with these parameters chosen based on physical phenomenon behavior and the Buckingham theory process for Appling the ANN approach to forecast breaking wave performance. When compared to the other parameters of fluid properties and wave characteristics, the results of mathematical dimension analysis with non-dimensional groups employed in ANN approach to predict the occurrence of breaking wave, the results shows a reasonable agreement that the ANN can be applied with R^2 equal to 97%.

Key words: ANN, Breaking waves, Buckingham theory.

Introduction

The main concepts of this study centered on breaking wave behavior, the most essential characteristics of waves that went from the sea to the beach. where H represents wave height as measured from the lowest point in the trough to the highest point in the crest, L represents the length of the distance between two successive crests for an individual wave, a represents wave amplitude as measured from the sea water level to the maximum height of the crest, and d represents the water depth as measured from the sea water level to the sea bed. (Al Shaikhli and Khassaf, 2021).

In relation to small amplitude wave theory, wave length L is a function of wave period T and water depth d, as indicated in equation (1), where wave period T is defined as the time it takes for the wave crest to travel from one location to the next. When the depth of water is equal to or more than half the length of the wave, like in deep water, the wave length L is solely a function of the wave period T, as indicated in equation (2). (Douglass and Krolak, 2008).

$$L = \frac{g\,T^2}{2\pi} tanh\left(\frac{2\pi\,d}{L}\right) \qquad \text{Eq. 1}$$

$$L = \frac{g\,T^2}{2\pi} \qquad \text{Eq. 2}$$

Where: g represents the gravity acceleration; m/sec^2.

Many studies attempted to understand the occurrence of wave breaking for different types of slopes, such as Stokes in 1847, these studies conducted for the slopes between (1:100 to 1:50) for irregular waves, as a result, the occurrence of wave breaking determined based on wave velocity and progression speed, according to these studies, two indices have been used to express the wave breaking occurrence, This index is commonly employed in deep water, whereas the other is (Hi/d), which is the ratio of the incidence wave height; Hi and the water depth; d. used in shallow water (McCowan, 1894).

McCowan, 1894, investigated and determined the wave breaking requirement of shallow water for horizontal bottom to occur when the ratio of wave height to water depth reaches 0.78, as shown in equation (3):

$$\frac{H_b}{d_b} = 0.78 \qquad \text{Eq. 3}$$

Where the subscribe symbol (b) refer to the inception of wave breaking state.

Miche, 1944, proposed a theoretical condition equation for breaking of waves that depends on hyperbolic tangent of wave angle, the equation used in deep water to give breaker index equal to 0.88, such that this condition raised the limit set by McCowan, 1894, as indicated in equation (4):

$$\frac{H_b}{L_b} = 0.142 \tanh\left(\frac{2\pi\, d_b}{L_b}\right) \qquad \text{Eq.4}$$

Le Méhauté and Koh, 1967, tried to understand the breaking wave behavior that reach to shoreline with an angle and to obtain breaking wave characteristics by proposing equation (5). This equation should satisfy the limits of bed slope; $\frac{1}{50} < m < \frac{1}{5}$ and the wave steepness ratio $\frac{H_o}{L_o}$.

$$\frac{H_b}{H_o} = 0.76\, m^{\frac{1}{7}} \left(\frac{H_o}{L_o}\right)^{-0.25} \qquad \text{Eq.5}$$

Where: m represent the bed slope of shoreline.

Goda, 1974, analysed laboratory data obtained by (Mitsuyasu, 1962 and Goda, 1964) in Japan to propose a new wave pressure formula for composite type of breakwater and summarised equation (6) for predicting braking wave index; this equation demonstrated that as bed slope increased, so did deep water braking index.

$$\frac{H_b}{L_o} = 0.17 \left[1 - e^{\left(-1.5\frac{\pi\, d_b}{L_o}\left(1+15\, m^{\frac{4}{3}}\right)\right)}\right] \qquad \text{Eq.6}$$

Ostendorf and Madsen, 1979, proposed modifying the parameters of Miche, 1944, equation to produce equation (7) with best fit equal to 0.8. Following that, the researchers presented two different equations (8 and 9), derived from Miche, 1944 equation, that take into account the effect of bed slope with two different ranges.

$$\frac{H_b}{L_b} = 0.142 \tanh\left(0.91\ \frac{2\pi\, d_b}{L_b}\right) \qquad \text{Eq.7}$$

$$\frac{H_b}{L_b} = 0.14 \tanh\left((0.8 + 5m)\frac{2\pi\, d_b}{L_b}\right) \qquad \text{for } m \le 0.1 \qquad \text{Eq.8}$$

$$\frac{H_b}{L_b} = 0.14 \tanh\left(0.13\ \frac{2\pi\, d_b}{L_b}\right) \qquad \text{for } m > 0.1 \qquad \text{Eq.9}$$

Smith and Kraus, 1991, carried out experimental study on submerged artificial reefs and bars breakwater, with a significant number of tests carried out under regular and erratic wave conditions. As indicated in the equation, a linear connection was developed for the breaking wave index in shallow water (10). The restrictions for using this equation should be met.

$$\frac{H_b}{d_b} = \frac{1.12}{1+e^{-60m}} + 5\left(1 - e^{-43}\right)\left(\frac{H_o}{L_o}\right) \qquad \text{Eq.10}$$

Where: $0.0007 \le \frac{H_o}{L_o} \le 0.0921$ and $\frac{1}{80} \le m \le \frac{1}{10}$

Hattori and Sakai, 1994, conducted laboratory experiments on permeable submerged breakwater and demonstrated that different porosities (0 to 0.52) of breakwater have an effect on breaking wave occurrence phenomenon, as rustles, offshore currents over submerged breakwater have an effect on breaking wave, offshore sea currents defined by the breaking wave index as present in equation (11).

$$\frac{H_b}{L_b} = \left(1 - 0.12\ \frac{R_c}{d_b} - 0.6\ \xi\right)\left(\frac{B}{5d_b}\right)^3 \frac{d}{L_o}\ \xi_s \qquad \text{Eq.11}$$

ISSN 2651-4451 | e-ISSN 2651-446X

Kawasaki and Iwata (1998) show statistically that crest width is an important element in determining breaking wave index. They conducted a study on impermeable rectangular submerged breakwaters, and the breaking wave index decreased as the crest width increased and the relative depth decreased. Following that, Kawasaki and Iwata, 2001, assumed that breaking wave index is dependent on submergence and incident wave heights. However, a study of impermeable trapezoidal submerged type of breakwater revealed that the bed slope and side slope of the breakwater have no effect on breaking wave index.

Rattanapitikon et al., 2003, established a new wave breaking index equation (20) for 695 instances based on re-analysis of previous laboratory results. Power form can be used to illustrate the connection between breaking wave and deep water steepness. Overall, equation (12) predicted agreement under a variety of experimental circumstances.

$$\frac{\mathrm{H_b}}{\mathrm{L_b}} = (-11.21\,\mathrm{m}^2 - 5.01\mathrm{m} - 0.91\,)\left(\frac{H_o}{L_o}\right)^{0.35} \qquad \text{Eq.12}$$

Yao et al., 2013, conducted a series of laboratory tests in a wave flume to explain the behavior of submerged reef breakwater, as a result, the ratio of the submergence to the wave height considered an important factor to describe wave breaking index as present in equation (13), top to that, the results showed that the influence of bed slope seems not important according to the studied experimental conditions.

$$\frac{H_\mathrm{b}}{d_\mathrm{b}} = \frac{Y_1 - Y_2}{2}\left\{tanh\left[\frac{\alpha}{1.4}\left(1.4 - \frac{R_c}{H_o}\right)\right] + \frac{Y_1 + Y_2}{Y_1 - Y_2}\right\} \qquad \text{Eq.13}$$

This equation can be applied when $0 \leq \frac{R_c}{H_o} \leq 2.8$ therefore, Y equal to Y_1 at $\frac{R_c}{H_o} = 0$, while Y equal to Y_2 at $\frac{R_c}{H_o} = 2.8$. The best fitting curves demonstrated that: $Y_1 = 1.07$, $Y_2 = 0.61$ and $\alpha = 3.24$.

Chiang et al., 2017 investigated sediment transport processes in coastal engineering under nonlinear wave impacts. For a theoretical background based on Stokes 2nd theory, the researchers combined (Le Méhauté and Koh, 1967) equation and (Goda, 1974) equation to develop equation (14) as shown:

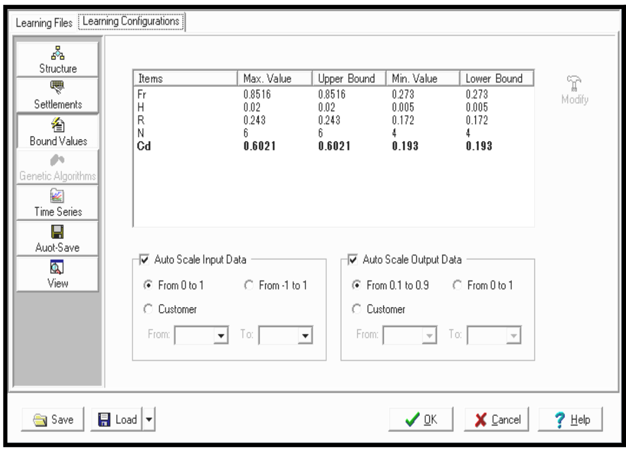
$$\frac{d_b}{L_o} = -\frac{\ln\left[1 - 4.47(m)^{\frac{1}{7}}\left(\frac{H_o}{L_o}\right)^{0.75}\right]}{1.5\pi\left(1 + 15\,m^{\frac{4}{3}}\right)} \qquad \text{Eq.14}$$

Artificial Neural Network Approach (ANN)

One of the most statistical processes in the world is the Artificial Neural Network (ANN). This system can handle the most complicated issues such that it appears like the human brain, using the interpolation and extrapolation to forecast the hydraulic characteristics of the phenomena. ANN is a neuronal mathematical model. A weighted summation of the output of prior neurons is provided for each neuron.

The neuron works using an activation function and a predictive value on this input. At least three major elements are contained in the ANN system, the first portion being nominated as an input layer, the second part as a cached layer and the third part as output layer. ANN system may include more than one hidden layer, and a learning value for each hidden layer is set to threshold input layer processing. In this work, sigmoid activation represented the results of the experiment of breaking wave, weights calculation using the Quick Propagation Algorithm (QP), and the link across neurons of each layer was Multiplayer Normal Feed Forwards to solve and transmit experimental breaking waves data (MNFF).

For ANN models structure, the predictive performance may be summed up in the form of an ANN i-j-k, that also denotes as (I) a neural input layer number, (j) a hidden layer number and (k) a neural output layer number. Neural Power software is an artificial intelligence system (ANN) used to calculate the weights and bias coefficients which minimizes mistakes in the output variables. The answer is stated in the current study that the root average square error is less than the minimum iterations (0.01). The momentum and learning rate values were selected as (0.8). As is recognized, due of the behavior of the sigmoid function the results of the ANN output never exceed one; in certain circumstances, data on the input and output layers should be scaled. In Figures (1) and (2), the learning arrangements and learning set-up solutions are presented.



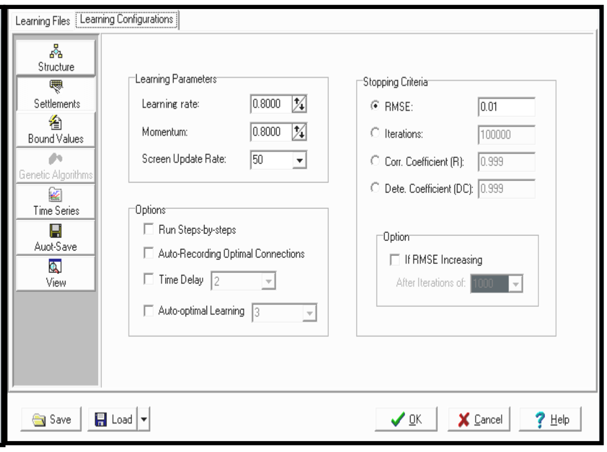


Figure 1: Learning configurations bound values. Figure 2: Learning configurations settlements.

The structure of ANN based on dimensional analysis shown in figure (3). The accuracy of the ANN model and also time to get the optimal solution that best matches the observed data on the researched phenomena according to the number of neurons in the hidden layer. Many hidden layer numbers were therefore checked and the number of layers that fulfilled RMSE was taken under 0.01. The weights of proposed model shown in table (1) and the compression of ANN results with experimental data for different wave heights shown in figure (4).

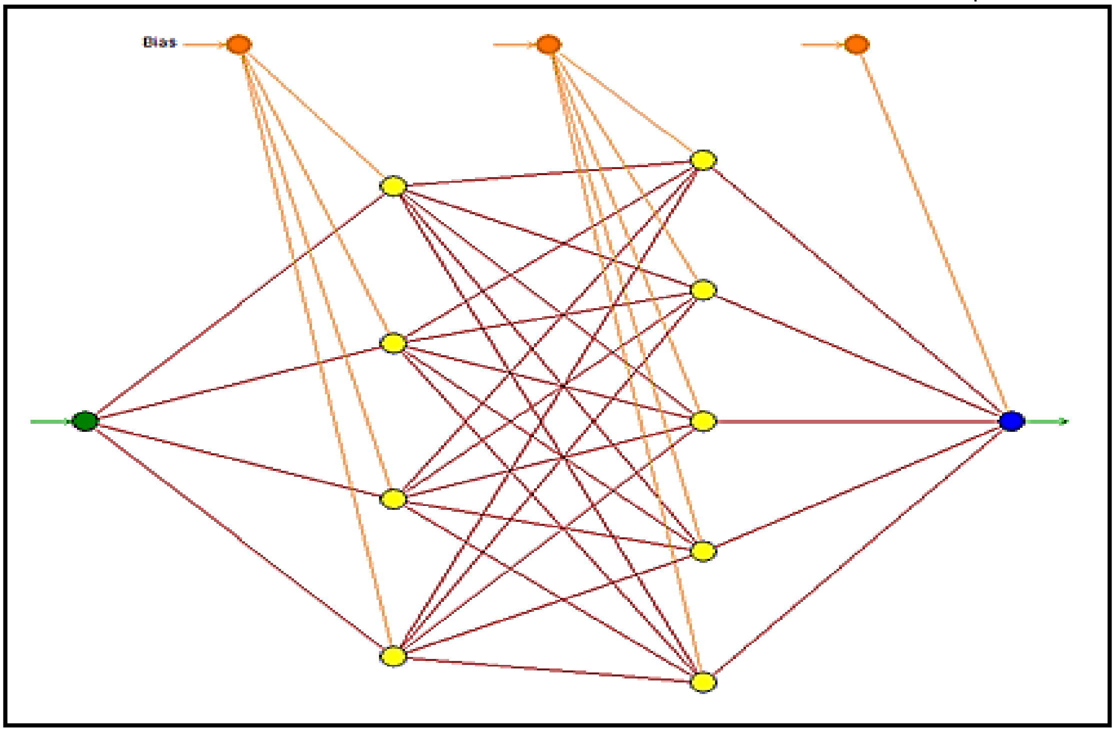


Figure 3: structure of ANN

Table 1: weights of proposed model

Connections	Weights	Connections	Weights	Connections	Weights
N1L1-N1L2	36.3128	N2L2-N1L3	4.0208	N4L2-N4L3	15.2149
N1L1-N2L2	33.4117	N2L2-N2L3	-96.1177	N4L2-N5L3	25.8194
N1L1-N3L2	2.9183	N2L2-N3L3	5.5276	B2-N1L3	3.5476
N1L1-N4L2	14.382	N2L2-N4L3	-44.7906	B2-N2L3	9.9492
B1-N1L2	13.4174	N2L2-N5L3	-5.6823	B2-N3L3	8.4346
B1-N2L2	17.0885	N3L2-N1L3	-0.6508	B2-N4L3	-22.7558
B1-N3L2	2.6482	N3L2-N2L3	11.3138	B2-N5L3	-1.0277
B1-N4L2	12.6832	N3L2-N3L3	-14.6246	N1L3-N1L4	-10.5121
N1L2-N1L3	-0.4988	N3L2-N4L3	5.6136	N2L3-N1L4	7.9679
N1L2-N2L3	11.7626	N3L2-N5L3	-15.2536	N3L3-N1L4	5.1614
N1L2-N3L3	0.4259	N4L2-N1L3	-2.4129	N4L3-N1L4	-3.6262
N1L2-N4L3	5.8116	N4L2-N2L3	-41.4203	N5L3-N1L4	-5.1303
N1L2-N5L3	1.6098	N4L2-N3L3	17.3155	B3-N1L4	-4.4022

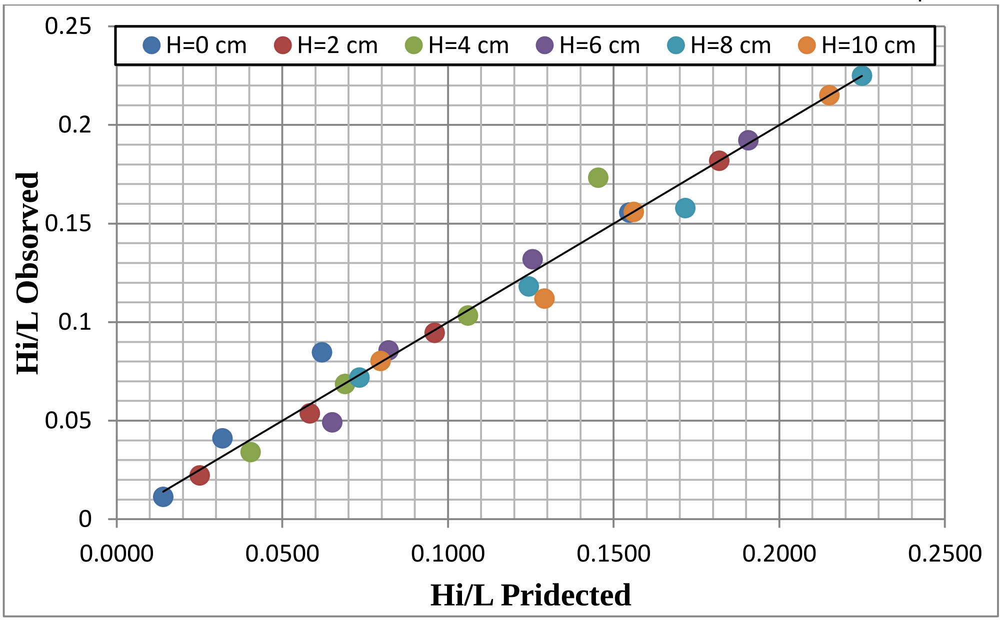


Figure 4: Observed VS predicted data curve

Conclusions

The wave behavior investigated taking into account the breaking conditions and the effects of all parameters to use ANN approach, using Buckingham theory as a mathematical dimension analysis technique with non-dimensional groups, shows that the parameters that have a major effect on the free surface phase at the braking waves can be employed in ANN approach to predict the occurrence of breaking wave and the results of ANN model shows a reasonable agreement with R^2 equal to 97%.

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ISSN 2651-4451 | e-ISSN 2651-446X

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