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Application of artificial neural network to predict the wave characteristics to improve the sea waves and currents forces applied on the jacket platform legs

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Abstract It is essential for all offshore structures analysis to estimate the forces generated by the wave and current by developing a program for modeling wave and current forces on offshore structural members. This study investigates the possibility of utilizing the relatively current technique of artificial neural networks (ANN) to predict the wave characteristics. Besides, the comparison of ANN models with the most two widely used empirical models included Bretschneider and Sverdrup-Munk and Bretschneider (SMB) equations showed a better performance for ANN models rather than empirical models. Furthermore, a developed program was studied for calibration and comparison purposes, where the program was checked against well-known professional software package called Structural Analysis Computer System (SACS). Airy wave theory (linear theory) has been implemented in the present study to calculate the water particles kinematics. Also, the Morison equation was used for converting the velocity and acceleration terms into resultant forces.
Keywords: Neural networks, offshore structures analysis, Airy's linear theory, SMB and Bretschneider equations, Morison equation

تطبيق الشبكة العصبية الاصطناعية للتنبؤ خصائص الموجة لتحسين قوة الأمواج والتيارات البحرية المؤثرة على قوائم المنصة الثابتة

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الملخص من الضروري لجميع التحليل للهياكل البحرية تقدير القوى الناتجة عن قوة الموجة والسحب من خلال تطوير برنامج لنمذجة الموجة والقوى الحالية على الأعضاء الهيكلية الخارجية. تبحث هذه الدراسة في إمكانية استخدام تقنية من تقنيات الذكاء الاصطناعي وهي شبكات العصبية الاصطناعية للتنبؤ بخصائص الموجة (ارتفاعها وزمنها). علاوة على ذلك ، أظهرت مقارنة بين الشبكة والنموذجين التجريبيين الأكثر استخداماً على نطاق واسع معادلات Bretschneider و SMB أداء أفضل لنماذج شبكات العصبية بدلاً من النماذج التجريبية. علاوة على ذلك ، تمت دراسة برنامج مطور لأغراض المعايرة والمقارنة ، حيث تم فحص البرنامج مقابل حزمة برامج احترافية معروفة تسمى نظام التحليل الهيكلي للكمبيوتر (SACS). تم تطبيق نظرية اري (النظرية الخطية) في هذه الدراسة لحساب حركيات جزيئات الماء. أيضا، تم استخدام معادلة موريسون لتحويل شروط السرعة والتسارع إلى القوات تؤاثر علي المنشأ.
الكلمات المفتاحية: الشبكات العصبية، تحليل الهياكل البحرية، نظرية آري الخطية، معادلات SMB و Bretschneider، معادلة وريسون.

Introduction

The protection of coastal environments is very important especially with more than 9,600 offshore fields worldwide. Offshore structures, such as platforms and wind Turbines are commonly adopted for such protection (Sadeghi, 2007). The major factor in coastal engineering design and analysis is a wave action which must be taken into account because much is known about wave mechanics when the wave height and period (or length) is known. Therefore, in last decades, the wind-wave models developed by numerical equations that based on empirical, simplified or parametric and numerical or elaborate methods as deterministic equations, these equations have became essential for a prediction of wave characteristics. However, researches have consistently shown that wave's generation by wind by using physical process is not yet fully understood which make them extremely complex and uncertain, also, the most advanced prediction need techniques which currently are not available in any laboratories because needs to highly advanced equipment, as well as the complexity of those models.

Many investigations and works for more than five decades such as (Darbyshire & Draper, 1963; Donelan, 1980; Mitsuyasu et al., 1980; Sverdrup & Munk, 1947; Toba, 1978) found that, many of uncertainty and empirical problems within an approximate structural analysis can be solved successfully by an alternative possible methodology, the method is Artificial Neural

Networks (ANN) that can be defined as connectionist systems which are computing systems inspired by the biological neural networks that constitute animal brains.

Artificial Neural Networks (ANNs)

ANNs is potentially useful in situations where the underlying physical process relationships are not fully understood and well-suited in modeling dynamic systems on a real-time basis. Also, ANN was originally introduced as simplified models of brain-function.

In this study, ANN applied to the prediction of the wave characteristics in the deep water conditions.

Hydrodynamic Forces

The hydrodynamic forces that acts on platform legs requires knowledge of vector of stress which includes gradients of the velocity and dynamic pressure. The wave forces on a vertical pipe were shown as illustrated in Figure 1:

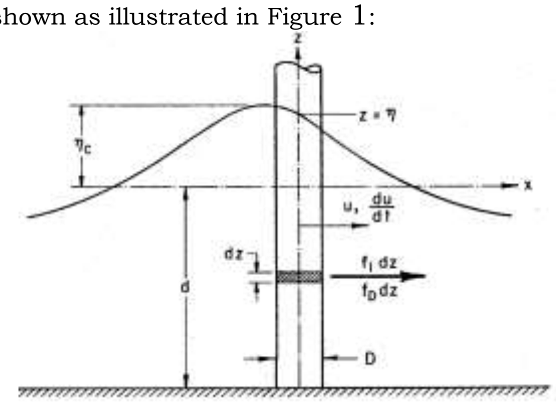

Fig. 1: Hydrodynamic forces parameters on platform legs due to waves (Sadeghi, 2007)

Methodology

To ensure the accurate prediction of a wave's characteristics by using artificial neural network (ANN) model which need to establish a reliable database. Accordingly, database was established by using numerical simulation of wave's characteristics and downtime done by authors, which were acceptable as an engineering application with correlation coefficient (R^2) by over 80%. From the prediction of wave's characteristics it can develop a program for modeling wave and current forces on a vertical and inclined cylinder offshore structural member. The predictions of wave characteristics based on equations as following:

S.M.B formulas

For deep-water conditions (Kabir, 2008):

$$\frac{gH}{U^2} = 0.283 \tanh\left[0.0125\left[\frac{gF}{U^2}\right]^{0.42}\right]$$

$$\frac{gT}{2\pi U} = 1.20 \tanh\left[0.077\left[\frac{gF}{U^2}\right]^{0.25}\right]$$

Bretschneider formulas

For deep-water conditions:

$$\frac{gH_{m0}}{U_A^2} = 1.6 \times 10^{-3}\left[\frac{gF}{U_A^2}\right]^{\frac{1}{2}}$$

$$\frac{gt}{U_A} = 6.88 \times 10\left[\frac{gF}{U_A^2}\right]^{\frac{2}{3}}$$

The graph that used to selecting the validity wave theory to yield the information on the wave motion in different waterdepths and for various environmental conditions is given in Figure 2.

Airy's linear theory provides an expression for vertical and horizontal velocity particle of water at place (x, y) and time (Sadeghi, 2007):

$$u = \frac{\omega H}{2}\frac{\cosh ky}{\sinh kd}\cos(kx - \omega t)$$

$$v = \frac{\omega H}{2}\frac{\sinh ky}{\sinh kd}\sin(kx - \omega t)$$

A spreadsheet has been developed to calculate manually the wake kinematics and the corresponding fluid forces, through Morison equation, for a cylinder which is considered to be in the vertical position.

The Morison formula is written below (Sadeghi, 2001):

$$f = \frac{1}{2}\rho C_D D \mid u \mid u + \rho C_I \frac{\pi D^2}{4} ax$$

Study Area

The Caspian Sea was selected as study area for this study as seen in Figure (3); the Caspian Sea is the largest enclosed basin in the world. As a result, important economic activities in the Caspian Sea, such as rich resources of oil and gas and the potential of transportation between Asia and Europe have made this sea vital.

Model Development

ANNs, can be defined as simplified models that established by layers which are consisting of a number of neurons, among the layers being interrelated by identical weights sets. The information that given in the form of initial input goes through the input layer as neurons, from which the different transfer functions are used to obtain the outputs.

The transfer functions that adopted in this study are expressed as:

a) Log-sigmoid transfer functions

$$f(x) = logsig(n) = \frac{1}{1 + e^{-n}}$$

b) Tan-sigmoid transfer function

$$f(x) = tansig(n) = \frac{2}{1 + e^{-2n}} - 1$$

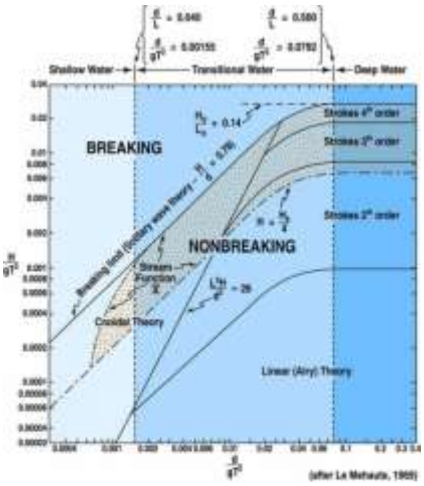

Fig. 2: Validity of wave theories graph (Sadeghi, 2007)

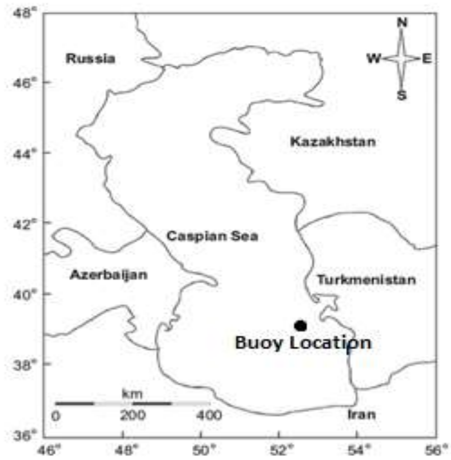

Fig. 3: Caspian Sea and the location of khazar buoy (Alhodairy, 2017)

In addition, neural network helps to model inputs in random environment to predict accurate output, besides; ANN application does not need to complex physical process as a precondition, which makes it applicable in various areas in yet to be proved (Alhodairy, 2017). The preliminary statistical analysis was the basis for formulating five predictions with more than 2300 inputs data. The cases differ from each other with regard to parameters for each of traditional wave prediction methods that practically based on S.M.B. and Bretschneider equations. Five different models were investigated. The models are labelled in Table (1):

Network Modeling

In this study, wave and wind characteristics were selected for training and testing of the networks. To evaluate the model performance, Correlation Coefficient (R^2) method was used. The parameters are defined as follows:

$$R^2 = \frac{\sum(Lo - Lo')(Lt - Lt')}{\sum(Lo - Lo')^2 \sum(Lt - Lt')^2}$$

Lo represents the wave height or wave period from observed data divided by number of the wave height; *Lt* represents the wave height from numerical model from the ANN model divided by number of the wave height.

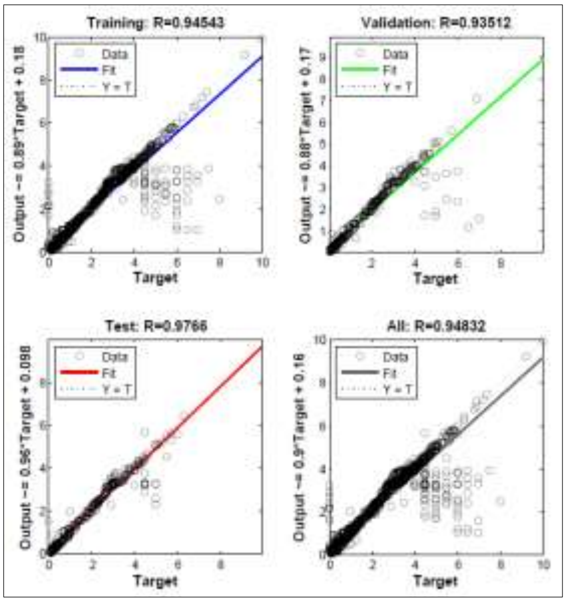

Fig. 4: Scatter diagrams for one of the study cases

For the study purpose, a feed forward-backpropagation network that contains different transfer functions (log and tan-sigmoid) as well as one hidden layer consisting of limited range of neurons was used. The training algorithm that adopted and implemented was the resilient backpropagation (trainrp) whit maximum epochs number in each simulation was used which is equal 1000; the ANN models were established within a MATLAB environment.

Table 1: Description of the modelled cases

Models	Parameters				
	Average wind speed (U10)	Fetch Length	Depth	Wind Duration	Corrected Wind Speed
(M 1.1)	√	√			
(M 1.2)	√	√	√		
(M 2.1.1)		√	√	√	√
(M 2.1.2)				√	√
(M 2.2)	√	√	√	√	√

Results and Discussion

These results are the most successful results among the ANN model tests conducted using these different parameters. The overall prediction for wave characteristics agree with observed data where the correlation of the ANN model and the wave characteristics height and period was approximately over 95%, which made this study acceptable for an engineering application. The five models are explained in short as following:

1) Model (1.1)

The results of this model shown in figure (5) shows that the use of 10 neurons layers gave best correlation and corresponding to three times training try improved the correlation coefficient of predict. Some changed was done in training parameters to improve the model performance. The best result is Case 1 with 97.7% (R^2).

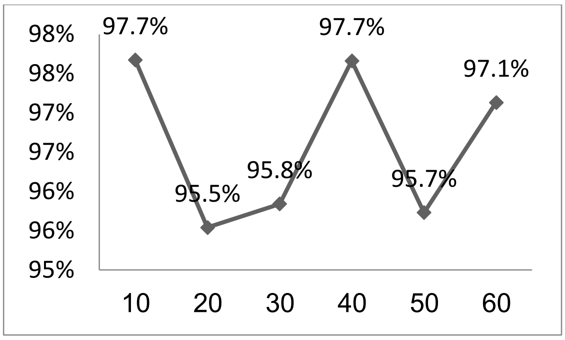

Fig.5: Network performance of (M 1.1) network according to no. of hidden neurons

2) Model (M 1.2)

A Clear disparity in predictions performance among all cases. As shown in Figure (6), the predictions of wave characteristics, using the ANN model (M 1.2), agree with the observed data. The results included two cases lower than 95%, but with changed in training parameters, (e.g. Initial weight) shows sufficient improvement in comparison with the previous results in case 6, where the result increase to 0.954 to 0.968.

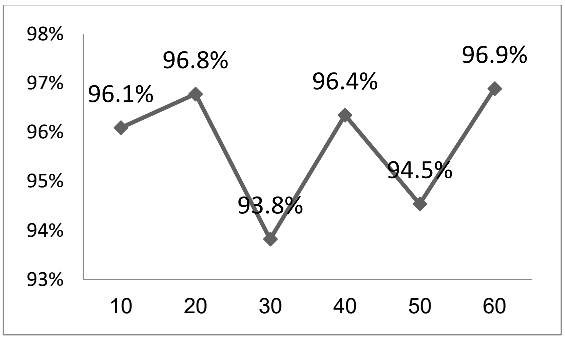

Fig.6: Network performance of (M 1.2) network according to no. of hidden neurons

3) Model (M 2.1.1)

The results that shown in figure (7) of the average prediction of wave characteristics using the ANN model (M 2.1.1) agree with the wave observed data with average correlation of the ANN model and the observed data more than 97%. The best result as shown in figure (7), which is demonstrated by (Case 5 (I.W. = 0.09)) with (R^2 = 97.64%).

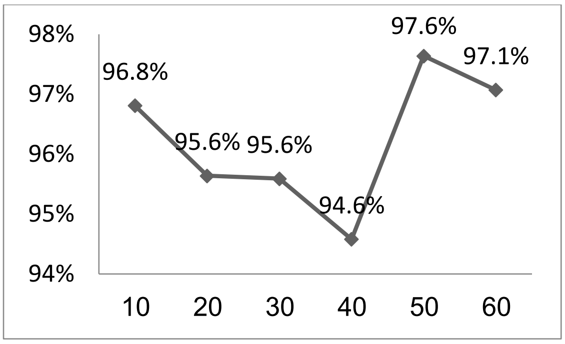

Fig.7: Network performance of (M2.1.1) network according to no. of hidden neurons

4) (M 2.1.2)

The overall best performance model was obtained with this model were relatively good with an even less number of nodes in both hidden and input layer(s) processing training with 97.91% (R^2). The rest of test results are shown in Figure (8).

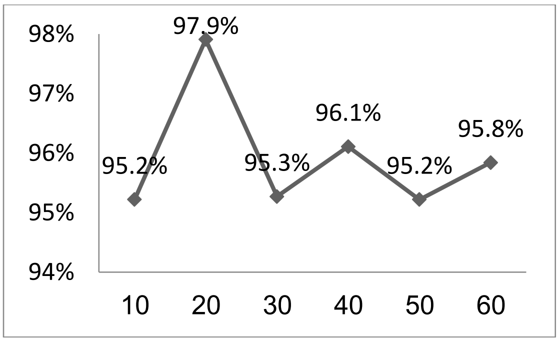

Fig.8: Network performance of (M2.1.2) network according to no. of hidden neurons

5) (M 2.2)

The results clearly indicate that the average of correlation coefficient is better than the previous ANN models, such as in model (M 1.1) and Case (M 2.1.1) where the R^2 is greater than 97% in almost two-thirds of model cases as seen in Figure (9).

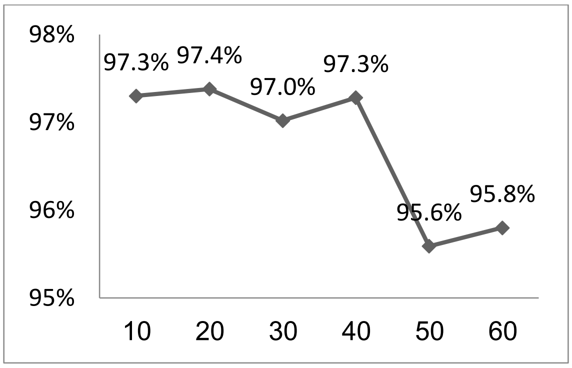

Fig.9: Network performance of (M 2.2) network zaccording to no. of hidden neurons

Wave loads

A spreadsheet has been developed to calculate manually the wave kinematics and the corresponding fluid forces, for a cylinder which is considered to be in the vertical position through Morison equation. The distributed wave force acting on that cylinder arising from the present study to calibrate and compare to the results of the

SACS program as shown in Figure (10). The wave parameters and cylinder details used in both of numerical examples are presented in Table 2.

Table 2: the wave parameters and cylinder details

Parameters	Value
Wave period (Sec.)	9.3
Gravity $(^{m}/_{s})^2$	9.81
Depth (m)	22.8
Wave height (m)	10.67
Diameter (m)	1.22
Density $(^{kg}/_{m^3})$	1030
Kinematic viscosity$(^{m^2}/_{s})$	1.17E-06

Conclusion

In this study, ANN was used for predicting the significant wave height and period values at buoy location in the south of the Caspian Sea.

A comparison of the various ANN models with prediction methods of wave height and period are established by equations of S.M.B.

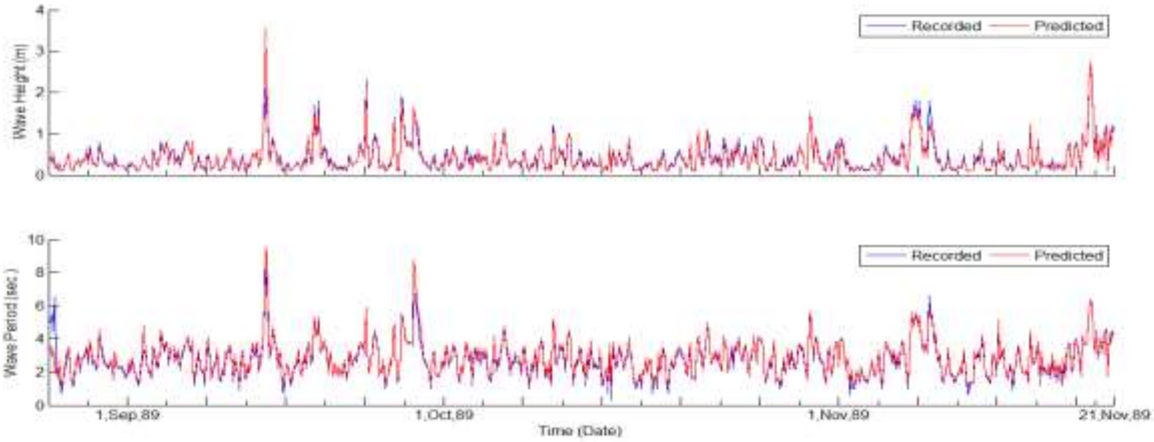

Fig.10: Predict wave characteristics using model (M 2.2) to H and T predicting.

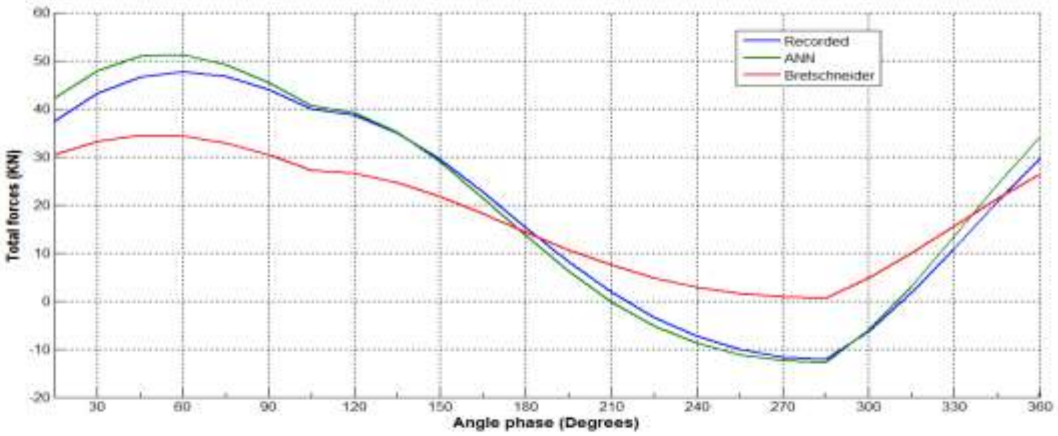

Fig.11: Comparison of total force from the maximum recorded wave data with the maximum of those predicted by Bretschneider equations and ANN.

(Sverdrup-Munk-Bretschneider) and there was a improvement in this study that reached to 96.73, 95.71 and 96.06 % better for ANN models (2.2), (2.1.1) and (1.1), respectively, in case to compared with the traditional numerical modeling as seen in Figure (10).

Moreover, the results of total forces were more accurate when the ANN wave parameters outputs employed within the Morison equations and gave closer results to these from recorded date as seen in Figure (11).

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References

[1]- Alhodairy, Y. (2017). Application of artificial neural network to predict the wave characteristics to improve the sea waves and currents forces applied on the jacket platform legs. Near East University.

[2]- Darbyshire, M., & Draper, L. (1963). Forecasting wind-generated sea waves. Engineering, 195, 482–484.

[3]- Donelan, M. A. (1980). Similarity theory applied to the forecasting of wave heights, periods and directions. National Water Research Institute.

[4]- Kabir, S. (2008). Significant Guidance for Design and Construction of Marine and Offshore Structures. GAU Journal of Soc. & Applied Sciences, 4(7), 67–92.

[5]- Mitsuyasu, H., Tasai, F., Suhara, T., Mizuno, S., Ohkusu, M., Honda, T., & Rikiishi, K. (1980). Observation of the power spectrum of ocean waves using a cloverleaf buoy. Journal of Physical Oceanography, 10(2), 286–296.

[6]- Sadeghi. (2001). Offshore Structure Engineering. Tehran: Dāneshgāh-e San'ate Ab va Bargh.

[7]- Sadeghi, K. (2007). An Overview of Design, Analysis, Construction and Installation of Offshore Petroleum Platforms Suitable for Cyprus Oil/Gas Fields. Soc. & Appl. Sci, 2(4), 1–16.

[8]- Sverdrup, H. U., & Munk, W. H. (1947). Wind, sea and swell. Theory of relations for forecasting. Pub. Hydrog. Office, Wash, (601).

[9]- Toba, Y. (1978). Stochastic form of the growth of wind waves in a single-parameter representation with physical implications. Journal of Physical Oceanography, 8(3), 494–507.