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APPLICATION OF ADOPTIVE NEUERO FUZZY INTERFACE SYSTEM (ANFIS) IN PREDICTING REFLECTION COEFFICIENT OF A PERFORATED QUARTER CIRCLE BREAKWATER

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ABSTRACT
Breakwaters are constructed for creating tranquil zone on the lee side to minimize the motion on ships due to the wave for easy handling of goods, apart from shoreline protection work etc. Due to the increase in demand for the coastal development all over the world, number of innovative Breakwaters was evolved as against the rubble mound. Recently, in order to further economize these innovative structures, Quarter Circular Breakwater (QCB) has been evolved. The coastal structure is subjected to hydrodynamic forces, involving various parameters while designing a safe and economical structure. The laboratory experiments are conducted in the wave flume in the National Institute of Technology, Surathkal Karnataka, India. In the present paper reflection coefficient (Kr) of a perforated QCB with S/D-3 (spacing to perforation diameter ratio) is predicted applying Adoptive Neuro Fuzzy Interface System (ANFIS) in MATLAB. The predicted values of reflection coefficient are compared with the experimental values.

INTRODUCTION
The main purpose of a Breakwater is to minimize the wave effect and provide a calm area for the development of a Port or Harbor. A Quarter Circular Breakwater (QCB) is a hollow caisson with flat horizontal base with a vertical face on its lee side and curvature towards the sea side. Due to its hollowness, the material required is considerably less enabling easy handling and placing the structure in the desired location. The whole structure is generally placed on a rubble mound base. The QCB can be impermeable or with perforation on the curved surface. Studies related to QCB are in the initial stages. Very few institutes have taken laboratory studies related to QCB because of time involved in each set of experiments. Due to the availability of fast computing technique, an attempt is made to predict the hydrodynamic performance of QCB by ANFIS using MATLAB.

LITERATURE REVIEW
Xi et al. (2005) studied the behavior of Quarter circular caisson type Breakwater (QCB). The caisson type of structures are hallow and even be placed on a weaker sub-strata.

Jiang et al. (2008) examined the performance of SBW and QCB in a 2D flume. It was noticed that no significant change in wave reflection coefficient of both QCB and SBW. As the depth of water decreased the value of Kr increased. During overtopping, a vortex near the rear walls of QCB is attributed to sharp corner and sudden expansion of flow around QCB.

Shi et al. (2011) investigated the hydrodynamic performance of QCB under both regular and irregular wave conditions. The wave reflection is analyzed, by two type of wave reflection coefficients as described by Shao et.al (2003) such as (i) Kr which represents the whole effect by the breakwater and (ii) Circular surface reflection coefficient (Kr), reflective effect by circular surface on the adjacent flow field. It was found that at the same relative freeboard, the value of Kr was higher than circular-surface reflection coefficient (Kr) has indicated that the reflective effect of QCB is stronger. They found that the loss of wave energy for emerged breakwater is larger than that for submerged breakwater.

Hegde and Ravikiran (2013) conducted experimental study on QCB to understand the effect of radius on reflection characteristics of submergence QCB. The study indicated Kr increases logarithmically as wave steepness increases.

Hafeeda (2014) conducted experiments in a two dimensional monochromatic wave flume on a seaside perforated QCB model. The data is analyzed by plotting the non-dimensional graphs of reflection coefficient for various values of wave steepness. The study indicated that Kr decreased with increase in d/hs and also as the free board is reduced effect of the curvature is less pronounced, thus, resulting, lesser dissipation energy and hence reflection. Binumol (2014) conducted physical model studies of QCB with three different radii and S/D (spacing to diameter of perforations) ratio, and analyzed dimensionless wave run-up and dimensionless wave run-down characteristics for different wave steepness. They reported that wave run-up increases with increase in wave steepness. At larger water depths, effect of curvature plays an important role resulting in lower run up and hence increases in wave rundown.

Balakrishna et al. (2015) reported that energy dissipation coefficient decreased with increase in wave steepness for different radii with same S/D ratio. Also, observed that as hS/D (significant wave height to water depth) increases, dissipation increases which is an opposite trend in the case of reflection.
Generally, computational intelligence techniques viz., Artificial Neural Network (ANN), support vector machine regression, genetic algorithm, etc., have been efficaciously proposed as an efficient tool for modelling and predictions in coastal engineering problems (Amr et al., 2011). In the present study, ANFIS is applied and model performance index are compared between experimental and predicted values of both reflection coefficient of a perforated QCB.

METHODOLOGY

The data used in the present study is from the Laboratory experiments are carried out National Institute of Technology, Surathkal Mangalore, in a wave flume of length 45.0 m x 1.0 m x 1.5 m on a Quarter circle Breakwater, fabricated with a steel plate having perforation of 0.016 m diameter with different spacing coveted with cement slurry, with the following as input parameters wave height (hi), water depth (d), wave period (T),Radius of the Quarter Circle varying its porosity below the water depth reduced as per the dimensional analysis, by Binumol et al at department of Applied Mechanics and Hydraulics, NITK, Surathkal, Mangaluru. Fiver parameters, such as incident wave height (hi), reflected wave height (hr), depth of water (d), radius of the breakwater and porosity below the water level (S/D) are considered. Principle component analysis (PCA) on all the five parameters is carried out to know effect of each input variable in obtaining reflection coefficient.

ANFIS model is developed by taking three variables which play prominent role as per PCA is used in predicting the reflection coefficient of QCB.

Adaptive Neuro Fuzzy Interface System

ANFIS is a kind of soft computing technique that is based on Takagi–Sugeno fuzzy interface system. The technique was developed in the early 1990s [1]. It integrates both neural networks and fuzzy logic principles and has the potential to capture the benefits of both in a single framework. The inference system corresponds to a set of fuzzy IF–THEN rules that have learning capability to approximate nonlinear functions [5].

The ANFIS architecture (Figure 1) has five layers, the first one being the input layer which also determines the membership functions. The degrees of each membership function are computed by the premise parameter set. The second layer generates the firing strengths for the rules. The third layer normalizes the computed firing strengths, by diving each value for the total firing strength. The fourth layer takes the normalized values as input and the consequence parameter set. The values returned by this layer are the defuzzificated ones and those values are passed to the last layer to return the final output.[8].

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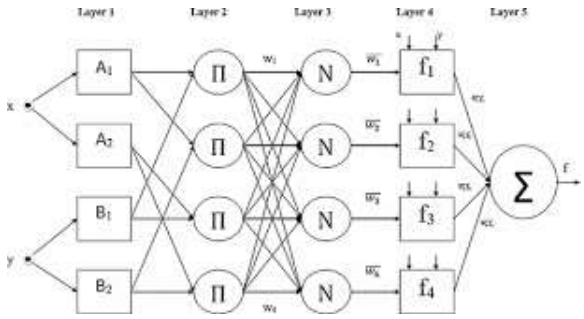

Figure 1 ANFIS Architecture

Layer 1
Every node in this layer is an adaptive node with a node function

Ol,i=μAi(x), for i=1,2 (1)
Ol,i=μBi-2(x), for i=3,4 (2)

x (or y) is the input node and Ai (or Bi−2) is a linguistic variable associated with the membership function of a fuzzy set (A1,A2,B,B2). A typical membership function:

$$\mu A(x) = \frac{1}{1+\left(\frac{c_i}{a_i}\right)^{2\, b_i}} \quad (3)$$

Where ai, and $ci$the parameter set. Parameters are called as premise parameters.

Layer 2
Each node in this layer is a fixed node, indicated by Π Norm. The output is the product of all the incoming signals.

O2,i=wi=μAi(x)·μBi(y), i=1,2 (4)
Output signal wi represents the fire strength of a rule.

Layer 3
Each node in this layer is a fixed node N form. The ith node calculates the ratio of the firing strength to the sum of the firing strength.
O3,i=w̄i=wiw1+w2, i=1,2 (5)
Output signal $\overline{wi}$ is called normalized firing strengths.

Layer 4
Each node in this layer is an adaptive node, indicated by square node with a node function:
O4,i=wifi=wi(pix+qiy+ri) (6)
Wherewi is the normalized firing strength from layer 3. {pi, qi, ri} is the parameter set which are called as consequent parameters.

Layer 5
Each node in this layer is a fixed node, indicated by circle node which computes the overall output as the summation of all incoming signals:
Overall output, S=O5,1=$\sum w_i\, f_i = \frac{\sum w_i f_i}{w_i}$ (7)
The different membership functions assigned for input parameters are:
Gauss membership function:

$$f(x, \sigma, c) = \frac{e^{-(x-\sigma)^2}}{2\, \sigma^2} \quad (8)$$

Where, x is input parameters, c and are mean and variance respectively.

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Triangular membership function:

$$f\ (x, a, b, c) = \max(\min(\frac{x-a}{b-a}, \frac{c-x}{c-b}), 0) \quad (9)$$

the feet of the triangle and b locate the peak.

Generalized bell-shaped membership function:

$$f\ (x, a, b, c) = \frac{1}{1+]x-ca[^{2a}} \quad (10)$$

where, x is input parameter, c locates the center of the curve.

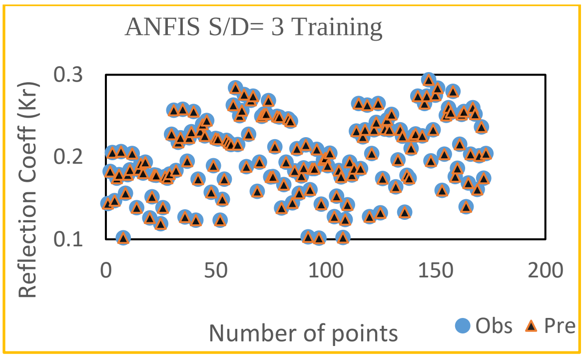
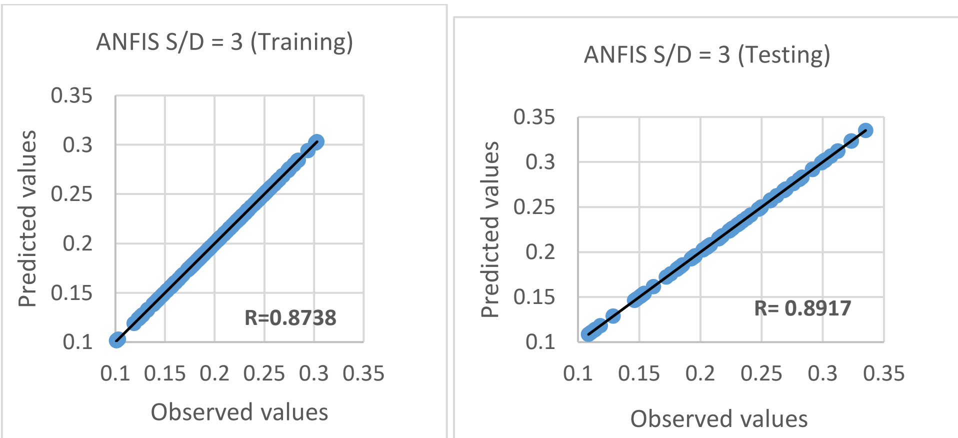


Figure 2.Plot showing observed and predicted values of K_r



(a) Testing set ***(b)Testing set***

Figure 3. (a) and (b) Observed Vs Predicted (Kr)

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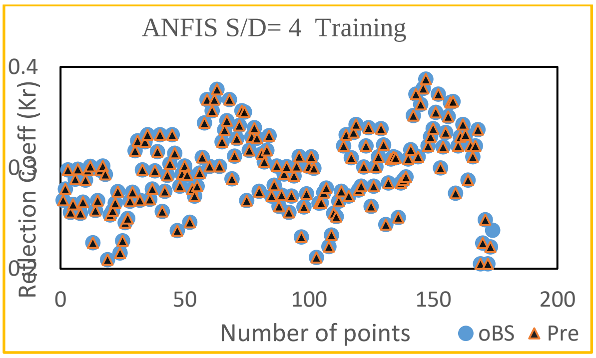
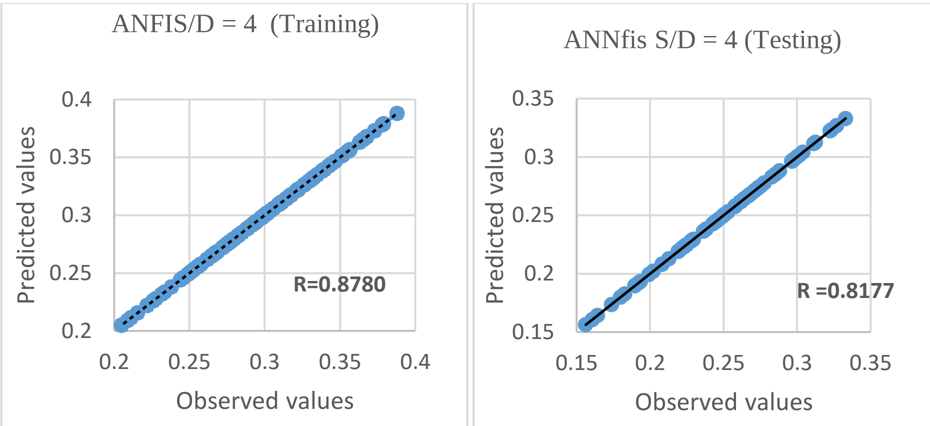


Figure 4.Plot showing observed and predicted values of K_r



(a)Training set ***(b) Testing set***

Figure 5. (a) and (b) Observed Vs Predicted (Kr)

Summary and Conclusions

The paper presented a study on application of ANFIS model with triangular membership functions for two different perforation conditions on the curvature of QCB for predicting the reflection QCB. The results obtained during training and testing process were evaluated by using statistical measures (Table 1) viz., coefficient of regression (R^2), root mean squared value (RMSE) and absolute mean error (ABS). On the basis of evaluation of the model results, the conclusions drawn from the study are given as below:

Table1 Statistical parameter of ANFIS models for predicting (K_r)

Statistical measures	S/D-3		S/D-4	
	Training	Testing	Training	Testing
R^2	0.814	0.802	0.878	0.873
MAE (%)	0.005	0.005	2.432	2.444
RMSE	0.004	0.003	0.009	0.008

a. The R^2 value of S/D-4 is comparatively better than the corresponding values of S/D-3, which confirms the lesser porosity has higher reflection from the breakwater surface.
b. The MAE of S/D-3 is less than its value of S/D-4 and the difference between the MAE values is computed as 2%.
c. RMSE value of S/D-3 indicates there is no difference between the observed and predicted values of reflection coefficient.

d. RMSE value of S/D-4 is higher than its values of S/D-3 during training and testing of the model.
On the basis of MAE and RMSE values, it is suggested that the scenario based on S/D-3 could be considered for computing the reflection coefficient though the R^2 value of S/D-3 is slightly less than the corresponding value of S/D-4.

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