# Fatigue Life Prediction of Reinforced Concrete Using Artificial Neural Network

**B. S. Vishnu, Keerthy M. Simon, and Bharati Raj**

**Abstract** Fatigue is a phenomenon of gradual, permanent internal changes in a material due to repeated or cyclic loading. The fatigue failure of structural elements may decreases the life of infrastructures, therefore the fatigue life of those structures should be considered. Highway and airfield pavements, bridge decks, offshore supporting structure, machinery foundation etc. are subjected to high cycle repeated loading. The randomness in parameters due to the heterogeneous nature of concrete due to fatigue loading leads to complexities in analysing fatigue failure of reinforced concrete. Probabilistic approach is more dependable for the prediction of fatigue life of reinforced concrete than deterministic approach as it can include variations and uncertainties. In recent years, artificial neural network emerged as a new promising computational tool which adopts a probabilistic approach for modelling complex relationships. The purpose of this study is to extract the data from fatigue tests conducted on reinforced concrete beam to create an artificial neural network predictive model. The developed model can able to predict the critical crack length of reinforced concrete members at which failure occurs by considering the fracture mechanics properties and material properties accountable for the softening behaviour of concrete as input. The developed ANN model and analytical model is capable of predicting the fatigue life of reinforced concrete with reasonable accuracy and in a faster approach.

**Keywords** Artificial neural network (ANN) · Fatigue life · Probabilistic approach · Reinforced concrete

## 1 Introduction

Concrete is the most commonly used materials used for the construction purpose. Although it is generally used it has some weakness also like low tensile strength, poor ductility, crack under tension, brittle failure, which leads to cracking. Cracking

B. S. Vishnu (✉) · K. M. Simon · B. Raj
Department of Civil Engineering, NSS College of Engineering, Palakkad, India

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2022

G. C. Marano et al. (eds.), *Proceedings of SECON'21*, Lecture Notes in Civil Engineering 171, https://doi.org/10.1007/978-3-030-80312-4_22

of concrete will affect the durability of structures and crack propagation will be more when structures subjected to fatigue loading.

Fatigue is the phenomenon of gradual, perpetual internal changes happening in a material due to repeated or cyclic loading. This leads to crack formation from the existing flaws within the material and results in fatigue fracture of materials. These may reduce the life of infrastructure and therefore the fatigue life of structures should be considered. Highway and airfield pavements, bridge decks, offshore supporting structure, machinery foundation etc. are subjected to high cycle repeated loading.. The randomness in parameters due to the heterogeneous nature of concrete due to fatigue loading leads to complexities in analysing fatigue failure of reinforced concrete. Fatigue life prediction of reinforced concrete is done by deterministic approach and probabilistic approach. Deterministic approach includes Fatigue life models, Fracture mechanics model and Fatigue damage model. Fatigue life method is not a proper method to find fatigue life concrete because it suffers from distinct property. For brittle and ductile material, fatigue life model is more applicable [1]. Fracture mechanics model is also extended from metals and comparing to fatigue life models, fracture mechanics gives a good prediction of fatigue failure of concrete. If varying parameters are their fracture mechanics model become more complex and is not dependable [2]. By the simultaneous presence of microcracks and macrocracks fatigue damage in concrete can be identified [3]. This model is applicable only for viscoelastic concrete.

Due to the disadvantages of the above-mentioned fatigue models, the importance of probabilistic approach came into importance for the fatigue life prediction of reinforced concrete. Probabilistic approach uses distributed values rather than fixed values. These distributed values have variations and uncertainty. Commonly used probabilistic approaches are Weibull distribution, Bayes rule and Artificial Neural Network (ANN). ANN is an effective computational tool developed by inspiring from biological nervous system. ANN can be used for fatigue life study by analyzing the given input data and output data [4].

## 2 Artificial Neural Network

ANN is developed as a part of artificial intelligence and having several interconnected artificial neurons. Neuron is a nonlinear unit which receives input signals yielding an output. ANN has three layers of neurons, Input layer which receives information, Hidden layer which perceives and evaluate the information from input layer, and Output layer which provides the final output. Based on problem to be solved ANN architecture is divided into Single layer Neural Network and Multilayer Neural Network.

## 2.1 Modelling of Neural Network

In this work, fatigue life of reinforced concrete in terms of relative crack depth is validated by collecting data from literature. These data were collected by considering the fracture mechanics properties and the material that accounts for the softening behaviour of concrete as input.

Neural network toolbox of MATLAB 2018a has been used to develop and train the model. The experimental and analytical data's reported by Sonalisa and Kishen [5] were used to develop, train and validate the model. The developed neural network architecture is based on multilayer perceptron network (MLPN) or multilayer feed-forward back propagation network. Levenberg-Marqaurdt back propagation algorithm was used for training algorithm as it gives an accurate result with lesser time and is more dependable for complex modelling problems.

The neural network is developed using the experimental data sets of reinforced concrete beam under four-point bending test of a fatigue load ΔP 24.75 kN. The geometrical properties and material parameters of the specimen are given in Table 1.

Considering the material and fracture mechanics properties necessary for the crack propagation to occur, the input parameters are chosen and is given in Table 2.

Relative crack depth at which failure occurs is chosen as output data. For modelling, the data sets were divided randomly and used as 70% for training, 15% for validation and 15% for testing. The network configuration adopted for developing the model was created according to specification given in Table 3.

Mean squared error (MSE) and regression value (R) were selected as performance criteria in order to identify the optimum number of hidden neurons which gives the best performing ANN model. The model with least MSE value and R value close to 1 was selected as the optimum neural network architecture and in this work the network with 7 neurons in hidden layer gives better results. Thus, the best architecture obtained gives MSE value as 0.0000003 and R value as 0.999 and have 6 input neuron, 7 hidden neuron and 1 output neuron (N 6-7-1) as shown in Figs. 1 and 2 shows neural architecture model.

**Table 1** Geometry and material property of specimen

| Sl no | Input parameter | Input range |
|---|---|---|
| 1 | Span $S$ (mm) | 1200 |
| 2 | Depth $D$ (mm) | 250 |
| 3 | Thickness $B$ (mm) | 150 |
| 4 | Notch size $a$ (mm) | 30 |
| 5 | Fracture toughness $G_f$ (N/mm) | 0.3 |
| 6 | Elastic modulus of concrete $E$ (MPa) | 16,500 |
| 7 | Tensile stress $\sigma_t$ (MPa) | 2.86 |

**Table 2.2** Details of input parameter

| No | Input parameter | Description |
|---|---|---|
| 1 | Number of cycles to failure | Number of cycles required for crack development |
| 2 | Structural size | Depth of the beam |
| 3 | Area of steel | Area of steel reinforcement in beam |
| 4 | Tensile stress | When major principal stress exceeds this value crack occur |
| 5 | Modulus of elasticity of concrete | Ratio of applied stress to corresponding strain |
| 6 | Energy release rate | Energy required by crack to propagate |

**Table 2.3** Neural network configuration for validation

| Parameter | Specification |
|---|---|
| No: of neurons in input layer | 6 |
| No: of neurons in hidden layer | 2–10 |
| No: of neurons in output layer | 1 |
| Training function | Levenberg–Marquardt (trainlm) |
| Activation function | Tan-sigmoid |
| Performance function | Mean squared error (MSE)<br>Regression value |

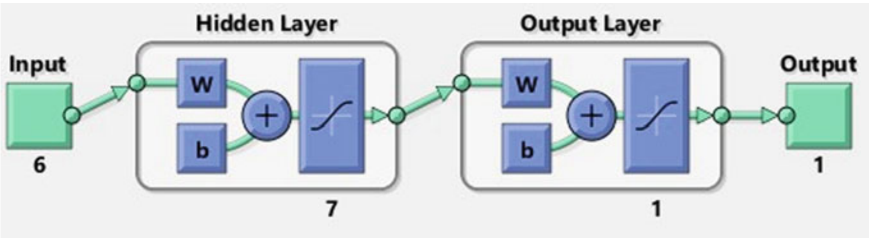


**Fig. 1** N 6-7-1 neural network architecture in MATLAB R2018a

## 2.2 *Evaluation of Network Model*

The performance of the developed neural network is evaluated based on Regression value (R). The model with R value closer to 1 represents the best model. Also, it is important to decide the number of neurons in the hidden layer to give the optimum network architecture. An optimal neural network can be obtained based on R value.

The reliability of the ANN model in predicting the relative crack depth at failure for data sets of reinforced concrete beam with R value of 0.999 is indicated in Fig. 3. The predicted output is mostly fit, indicating the accuracy of prediction in

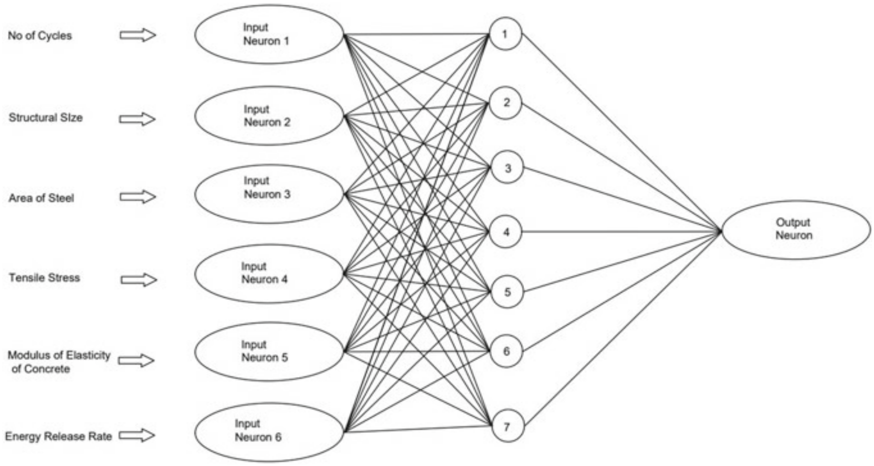


**Fig. 2** Neural Network Architecture Model

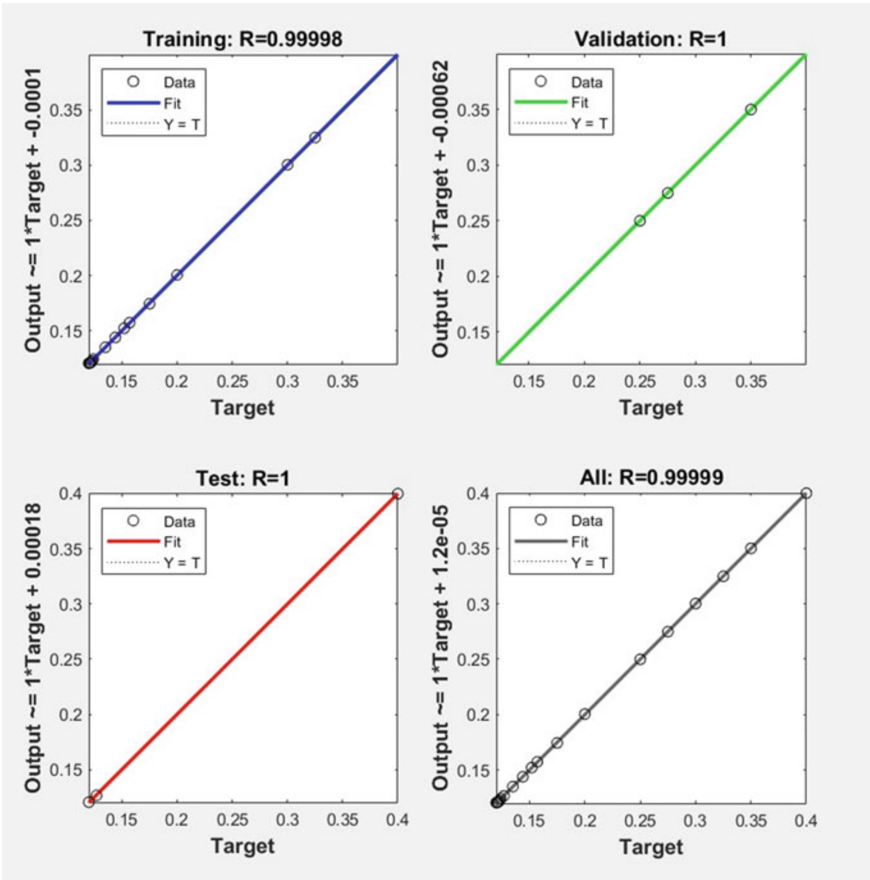


**Fig. 3** Regression plots for training, validation, testing, and overall data in MATLAB R2018a

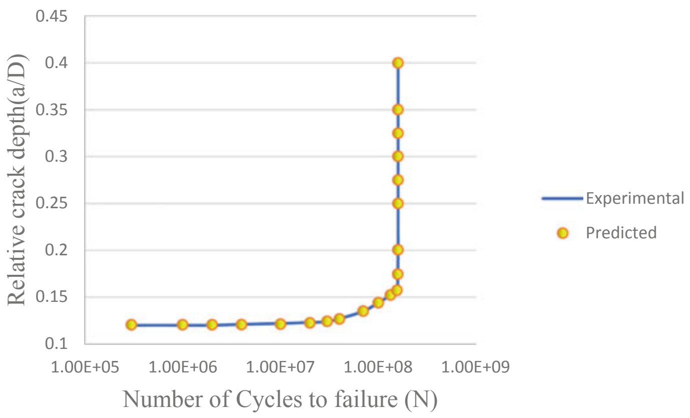


**Fig. 4** Comparison of relative crack depth with number of cycles using the predicted output with experimental results

ANN tool. The graph is plotted comparing the experimentally obtained result and predicted output of relative crack depth with number of cycles in log scale for the specimen are given in Fig. 4. A good agreement is seen between the experimental results and the predicted output. The validation results are within 1% error and hence the developed model can predict the fatigue life of reinforced concrete beams with considerable accuracy.

## 3 Conclusions

This work deals with the validation of fatigue life prediction model for reinforced concrete by using ANN.

- In this work, fatigue life prediction model for reinforced concrete proposed by Sonalisa et al. is validated
- Validation is done by considering 2–10 neurons in hidden layer and model with 7 neurons gives the most accurate result
- The best architecture model obtained gives MSE value as 0.0000003 and R value as 0.999
- A graph is plotted for comparing the experimentally obtained result and predicted output of relative crack length with number of cycles to failure
- This developed model can predict the relative crack depth with less than 1% error in a faster approach.

## References

1. Miner MA (1945) Cumulative damage in fatigue. J Appl Mech 12(3):159–164
2. Slowik V, Plizzari GA, Saouma VE (1996) Fracture of concrete under variable amplitude fatigue loading. ACI Mater J 93(3):272–283
3. Pervaiz Fathima KM, Chandra Kishen JM (2015) A thermodynamic correlation between damage and fracture as applied to concrete fatigue. Eng Fract Mech 145:1–20
4. Hajela P, Berke L (1991) Neurobiological computational modes in structural analysis and design. Comput Struct 41:657–667
5. Ray S, Chandra Kishen JM (2014) Analysis of fatigue crack growth in reinforced concrete beams. Mater Struct 1:47(1–2):183–198