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# Artificial Neural Network Modelling Approach to Predict the Effect of CFRP Composites on the Axial Strength of Rectangular and Square Columns

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## ABSTRACT

The purpose of this study is to offer an analytical model based on artificial neural networks (ANN's) that can predict axial strength of Corbon fibre reinforced polymers (CFRP)-confined concrete columns. The novel aspect of the suggested model is the way an analytical relationship is formulated without taking into account the conventional effectiveness parameter that is frequently present in models that are published in the literature. Using an experimental database from the literature, the ANNs were trained and evaluated. The database held various input parameters, such as the cross-sectional details, corner radius, initial compressive strength of concrete, longitudinal reinforcement ratio, Reinforcement tensile strength, , number of layers of CFRP, thickness of CFRP layers, and tensile e-modulus of CFRP, in addition to that one output parameter representing the final axial capacity of concrete Columns. It is advised to use the suggested model for rectangular columns that have continuous Unidirectional CFRP wrapping. The testing of model indicates the predictions' correctness, and an experimental vs prediction comparison verifies their accuracy. The findings show that the suggested model is accurate with correlation factor (R) of 0.99869 and is suitable for the design of CFRP-confined concrete.

**KEYWORDS:** Concrete, Artificial Neural Networks, CFRP, Column, Confinement

## 1 INTRODUCTION

There are several techniques available in literature to strengthen a concrete columns like Cross section enlargement using steel and concrete encasing. [1] But these techniques are disruptive, difficult to apply and cause high geometry changes in the structure. [2] Therefore mostly reinforced concrete structures that have failed because of poor design, poor construction, or natural calamities like earthquakes are frequently strengthened using fibre-reinforced polymers (FRPs) [3-7]. FRP materials are used as a sophisticated structural engineering technology to enhance structural elements made of reinforced concrete [6–10]. The use of CFRP wraps for confinement of load bearing members like columns highly improves their ductility and compression strength. This improvement in strength is observed because of the CFRP composites' high strength–to–weight ratio and their ease of application in confined places, and ease of handling on the job site is also make them useful material for rehabilitation [11–19]. CFRP composites are novel materials that stiffen and strengthen structural parts, according to [20–23]. Numerous investigations have been performed to see the performance of CFRP in circular cross sections [24–26]. Because of this, numerous confinement equations were created to calculate the maximum axial loading capacity of structures [27]. The FRP-confining phenomenon is addressed using two methods: Design-Oriented Modelling (DOM) and Analysis-Oriented Modelling (AOM). The main difference is that the AOM provides the behaviour curve of the confined column in terms of the stress-strain, whereas the DOM merely provides the value of the stress and strain at the ultimate point, as is explained in detail in [28]. Most of the strength models that were in use for FRP-confined concrete embraced the theory that was anticipated by [29–30], respectively. This theory states that the ultimate strength of concrete that is hydrostatically constrained takes the following shape.:

$$f'cc = f'_{co} + k_1.f_1 \qquad (1)$$

$f'cc$ is the constrained column's compressive strength.
$f'_{co}$ is the column's unconfined compressive strength.
$k_1$ is the dimensionless coefficient of confinement efficacy.
$f_1$ is confining pressure that the FRP-containment provides, which is thought to be equivalent to Ef efu.
efu is the FRP-sheet's ultimate strain, and Ef is its elastic modulus.

Artificial Neural Networks (ANN's) can be used to provide great predictions for problems that are hard to characterize with a single model [31–33]. A non-parametric model with a high ability to learn complex nonlinear correlations between variables is an ANN [34–37]. Based on an experimental database ANN is used in many investigations to study the effect of confinement, Pham and Hadi [38] employed ANNs to predict the compressive strength and strain of FRP-confined columns. They concluded that the strain and compressive strength of FRP confined concrete columns have been successfully determined using ANN's. Moreover, ANNs were used in the creation of novel mathematical models by Yousif [39] and Khan et al. [40] to predict the FRP confined compressive strength of circular concrete columns. It was discovered that the ANN technique worked well and consistently while building mathematical models.

## 2 METHODOLOGY AND SIGNFICANCE OF STIDY

Creating an ANN model for axial capacity prediction of rectangular columns covered with CFRPs is the main purpose of the current study. To do this, a database of 195 Specimen from the previous investigations was subjected to neural network modelling. After the data collection, All the collected data was normalised and used to train the ANN model. Different architectures and training algorithms were tried until the best model with most accurate prediction is obtained.
The present work supports the analysis and design of rectangular CFRP-covered columns by structural engineers. Therefore, the ANN model developed through this investigation can be used effectively in the design process of repairing/strengthening square/rectangular concrete columns with CFRP Composites

# 3 ANN MODEL

## 3.1 DATA COLLECTION AND SCALING

In current study an ANN model is developed that estimates the axial capacity of rectangular columns confined by CFRP using a database of 195 input–output sets acquired from references of the experimental research [41–47], considering a wide range of significant properties. The issue related to learning rate of model is countered by normalising the collected data values by assigning the optimum upper and lower limit. [48] Hence to make the results of predictions more accurate all the collected data was scaled between 0-1 by max-min scaling rule by equation 2.

$$y = \frac{x - x_{min}}{x_{max} - x_{min}} \qquad (2)$$

Where y is the normalised value and x is the value of variable collected from literature. Meanwhile $x_{max}$ *and* $x_{min}$ are the maximum and minimum value of a respective variable. Data is automatically distributed into 15 percent validation, 15 percent testing and 70 percent training through MATLAB [49,50]. To avoid any overlapping of data during validation, 6 cross-validations are introduced while training the model. Statistical analysis of the collected data from literature is presented in Table 1.

*Table 1: Statistical analysis of Collected data.*

| Variables | Units | Lowest | Highest | Diff. | Avg. | SD |
|---|---|---|---|---|---|---|
| **Columns Length** | mm | 150 | 600 | 450 | 179 | 85 |
| **Columns Width** | mm | 94 | 600 | 506 | 192 | 92 |
| **Corner Radius** | mm | 0 | 96 | 96 | 26 | 19 |
| **Column Height** | mm | 300 | 3000 | 2700 | 481 | 447 |
| **Initial Compressive Strength of Concrete** | Mpa | 24.51 | 61.5 | 36.99 | 35 | 8.932 |
| **Initial Tensile Strngth of steel** | Mpa | 0 | 414 | 414 | 37 | 117 |
| **As/Ag** | % | 0 | 1.6 | 1.6 | 0 | 0.413 |
| **Layers of CFRP** | No's | 0 | 5 | 5 | 1 | 1.164 |
| **CFRP thickness** | mm | 0 | 0.3 | 0.3 | 0 | 0.091 |
| **Tensile E-modulus of CFRP** | GPa | 0 | 255 | 255 | 149 | 105 |
| **Confined Axial Capacity** | kN | 401.15 | 16970 | 16568.8 | 2757 | 3836 |

From Table 1 it can be observed that the parameters collected from experimental investigations in literature has a huge range of variation in the values. For instance, if corner radius is concerned, the collected data has variation from 0 to 96 mm to undertake the effect of corner radius on rectangular columns. Similarly compressive strength of concrete and number of CFRP layers varies from 25-60 Mpa and 0-5 No's. Hence the collected data shows a very wide range of different parameters hence the produced ANN model can be utilised for predictions during practical designs.

## 3.2 MODEL TRAINING TESTING AND VALIDATION

MATLAB [49,50] is used to construct the ANN model in the current investigation, The model for rectangular columns is proposed utilising the multilayer feed-forward NNs (MLFNNs) technique. The fully connected, three-layer feedforward network structure is the most used in supervised learning. In ANN networks, every neuron in the hidden layer is linked to the input values. The network's output is generated by the activations of its output neurons, which are coupled to every other neuron in the output layer by means of the outputs of the hidden neurons. The most optimal network design is shown in Figure 1 having one hidden layer and 10 neurons in it.

There are 14 functions available in MATLAB [49,50] to train an ANN model. Among them Levenberg–Marquardt, Bayesian regularization, BFGS Quasi-Newton and Resilient back propagation are used in this study. A correlation factor (R) of 0.99869, 0.99618, 0.89299, 0.80723 is obtained through different training algorithms like TrainLM, TrainBR, TrainBFG and TrainRP respectively. Hence TrainLM is found out to be the most optimum learning algorithm to train the under-consideration ANN model, its correlation factor of training, validation and testing is presented in Figure 2.

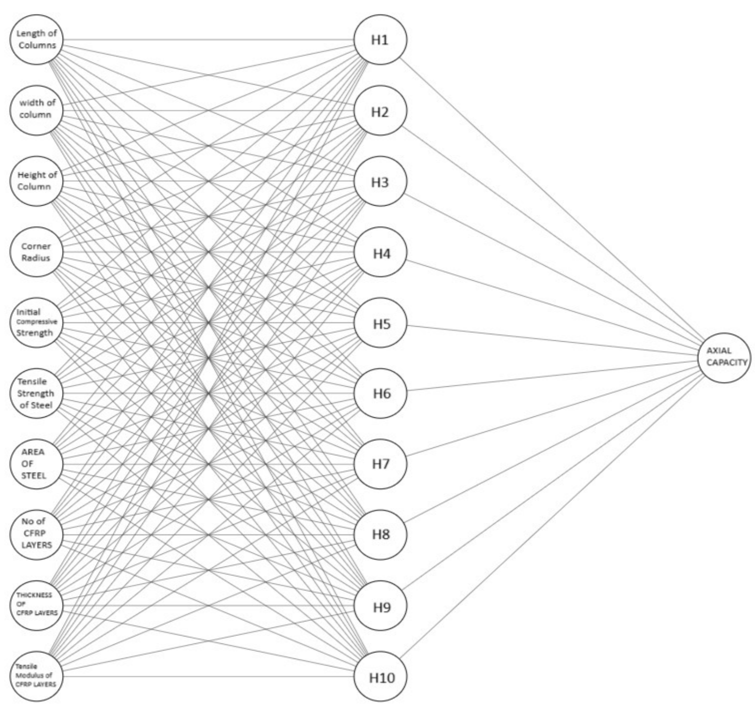


*Figure 1: Structure of Proposed ANN Model*

The predictions from the trained model shown that the predicted values are very close to the original experimental values collected from literature. As shown in Table 2 the average predicted value of confined axial capacity is 2765 Mpa meanwhile the average confined axial capacity of columns from collected data was 2757 Mpa. Hence the average error is negligible and as low as 0.27%.

*Table 2: Statistical analysis of confined Axial capacity from model and data*

| Technique | Highest | Lowest | Difference | Average | St. Dev |
|---|---|---|---|---|---|
| From Data | 401.15 | 16970 | 16568.8456 | 2757 | 3836 |
| From Model | 421.5 | 16631 | 15772.60 | 2765 | 3828 |

Even though the produced results are very impressive and accurate enough to be used for design purposes but still greater the dataset greater would be the accuracy of predictions. Moreover, in literature too much research is done on short columns or concrete cylinders, but limited research is available about full length concrete columns confined with CFRP. Therefore, it is advised and recommended that more research should be conducted on full sized concrete columns to improve the performance of the developed ANN model.

## 4 RESULTS AND DISCUSSIONS

With ANN model, a relationship between a variety of input parameters and the output value was established. The correlation factor (R) of the best model is presented in Figure 3. The maximal strength of CFRP-confined square specimens increases with increasing CFRP thickness and its layers. Comparing to the control specimen, the square specimen with one layer of CFRP failed at a compressive strength that was over 25% greater. Using two CFRP layers increased compressive strength by 50%. In comparison to the unconfined specimen, the compressive strength of the rectangular specimen with a (L/W) ratio of 1.5 and one layer of CFRP increased by 15%, while in the case of (L/W) ratio of 1.5 and two layers of CFRP, it increased by 35%. The one-layer CFRP and rectangular specimen with a (L/W) ratio of 2 failed at a compressive strength that was 24% greater than the control specimen. Similarly, the maximum increase in compressive strength was 50% in a rectangular specimen with two layers of CFRP and a (L/W) ratio of 2.

The specimen that is rectangular in shape and has (L/W) ratio of 1.5 exhibits 4% greater compressive strength than the square specimen that is wrapped in a single layer of CFRP. On the other hand, the compressive strength of a rectangular specimen with a (L/W) ratio of 2 increases by 15%. The compressive strength of rectangular specimens wrapped in two layers of CFRP wrapping with an L/W ratio of 1.5 is 3% higher than that of square specimens wrapped in the same amount of CFRP. Comparing the rectangular specimen with a (L/W) ratio of two to the same specimen, the compressive strength of the former is 15% greater. The increase in compressive strength is less noticeable when comparing two CFRP layers to one CFRP layer.

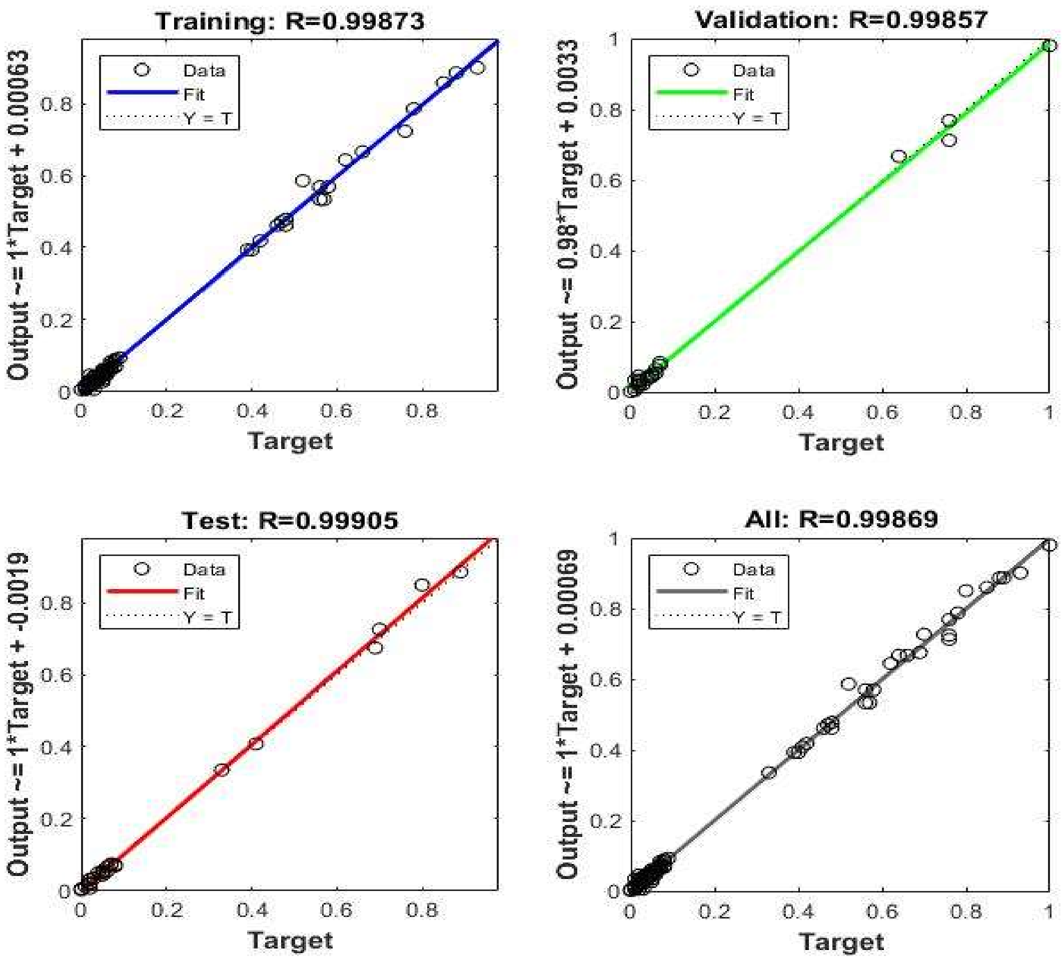


*Figure 2: The correlation between predicted and experimental Axial Strength*

## 5 CONCLUSIONS

Among the several factors influencing the CFRP-confined concrete's compressive strength are its geometrical and mechanical characteristics. Thanks to a dataset collection containing 195 specimens, an ANN-based analytical model can be generated utilizing a representative statistical population. The proposed model has demonstrated how important elements impact compressive strength, such as the cross section of the column, the compressive strength of the unconfined concrete, the thickness of the CFRP, and its Young's modulus. The output value of the model was stated as a dimensionless parameter that would yield the equivalent compressive strength due to the CFRP-confining action. By increasing the size of the column cross-section, the number of

CFRP layers, and the compressive strength of the concrete, the ultimate load capacity of the CFRP confined RC columns is significantly increased.
The experimental approach may be quite costly and time-consuming. Using the developed ANN model having correlation factor (R) of 0.99869, CFRP constrained rectangular reinforced concrete columns can be analysed and designed using any combination of the column cross section, concrete's compressive and tensile strengths, longitudinal reinforcement ratio, CFRP thickness, CFRP modulus, and other parameters.

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