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Applying machine learning in Predicting the effect of cross-sectional shape on the axial strength of thermally damaged and CFRP-repaired concrete columns

Muhammad Salman
Civil Engineering Department, University of engineering And Technology, Taxila
MMSalman02@gmail.com

Muhammad Faizan
Computer Engineering Department, University of engineering And Technology, Taxila
Faf2001f@gmail.com

Muhammad Noman, Monisa Salati
Civil Engineering Department, University of engineering And Technology, Taxila
Muhammadnoman4188@gmail.com, Monisasalati21@gmail.com

ABSTRACT

This paper investigates the influence of cross-sectional shape on the axial strength of thermally damaged concrete columns repaired with Carbon Fiber Reinforced Polymer (CFRP) using Artificial Neural Network (ANN) modeling. Two artificial neural network models are made, one for rectangular column data sets and the second for circular column datasets. This study integrates these models to assess the performance of columns with varying cross-sectional shapes under fire exposure. A comprehensive dataset, derived from both rectangular and circular columns, was utilized, encompassing key parameters such as column dimensions, initial material strengths, fire temperature, exposure duration, and CFRP confinement properties. The ANN model demonstrated a high correlation with experimental data, effectively predicting the ultimate axial strength of CFRP-repaired columns across different shapes. The findings offer valuable insights for structural engineers in optimizing repair strategies for fire-damaged columns, highlighting the critical role of cross-sectional shape in the rehabilitation process.

Keywords

Machine learning, Artificial Neural Network, Concrete columns, Fire damage, CFRP

1. Introduction

Natural fires are terrible yet prevalent. Uncontrolled, it can have significant impacts on its surrounds. The number of structures damaged by fire accidents is rising globally. Concrete structures have substantial damage risk due to lost structural integrity during and after fire activity (Mathews, Anand, Kodur, Arulraj, & Buildings, 2021). To reduce financial losses from closed and unusable facilities, building owners and insurers require speedy, reliable, and cost-effective fire restoration solutions. Many ways have been used to strengthen columns, such as section enlargement and steel jacketing. Nowadays, fiber-reinforced polymer (FRP) is the favored strengthening material because to its speed and light weight. Research indicates that FRP jacketing can quickly and easily strengthen and repair damaged structures. (Chinthapalli & Agarwal, 2020)

Retrofitting concrete columns with FRP has been extensively studied for non-fire damage (Turgay et al., 2010), but there has been little research on fire-damaged square/rectangular concrete columns. Limited study exists on the behavior of FRP in fires after repair due to uncertainty (Demers & Neale, 1999; Moghtadernejad, Jamshidi, Maheri, & Keong, 2021; Yaqub, Bailey, & Materials, 2011). Scientific and technical breakthroughs have led to the application of machine learning (ML) and artificial intelligence (AI) in various industries. Deep learning has been popular for addressing various technical difficulties (Takemura, 1997). Previous study has predicted FRP constrained concrete compressive capacity using neural networks (NNs) (H. Al-Nimry, Haddad, Afram, Abdel-Halim, & structures, 2013). NNs reveal a promising approach for assessing FRP concrete's limited compressive strength using material and structural factors. Neural networks are used in literature to predict compressive strength, fire resistance, residual strength, and high-temperature damage in confined columns. (Le-Nguyen, Minh, Ahmad, Ho, & Engineering, 2022). If neural network (NN) modeling of present study is evaluated, No research exists on the DNN model for analyzing the impact of CFRP on heat-damaged rectangular columns.

The axial strength of concrete columns is substantially influenced by their cross-sectional shape. Typical shapes of columns include round, square, and rectangular, each exhibiting distinct failure mechanisms and load capabilities when subjected to varying stress situations. Circular columns have superior performance when subjected to axial loads because they have a more even distribution of stress. In contrast, square and rectangular columns are more prone to stress concentration, especially at the corners. Recent studies highlight that the cross-sectional geometry of columns can significantly influence their behavior, particularly when exposed to non-uniform thermal damage (Yaqub, Bailey, Nedwell, & Composites, 2011)

It is established that the FRP jackets effectively confined the circular-cross-sectioned RC columns. The cross sections of most RC columns used in real-world applications are square or rectangular. Due to the inadequate confinement of the whole rectangular area, the behavior of FRP-confined rectangular columns differs significantly from that of circular columns wrapped in FRP. In columns with rectangular Cross-section, the constraining effect is centered in the areas closest to the corners. An arc action (Yaqub, Bailey, & Materials, 2011) is the term used to describe this confinement distribution in a rectangular cross-section as shown in Fig. 1.. Put another way, the number of CFRP layers and the geometry of the column cross-section determine the confining pressure and, ultimately, the efficacy of the confinement

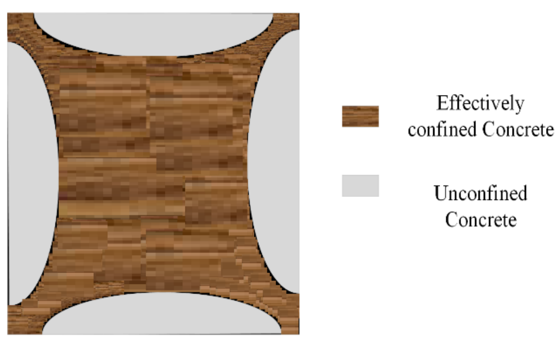

Figure 1 Arching effect in Rectangular and square Columns

2. Methodology

A database of 143 rectangular specimens and 125 circular specimens were culled from literature in order to develop a successful deep neural network model for predicting the axial capacity of square, rectangular, and circular concrete columns that had been destroyed by fire or rebuilt using CFRP. After that, the data was standardized before being used to train the DNN models. Two DNN models, one using a rectangular column and one using a circular column, were created, each with its own unique neural architecture. The DNN models for predicting the axial capacity of fire-damaged concrete columns repaired with CFRP were developed using a multilayer feed forward NNs (MLFNNs) technique. After evaluating the output strength models, the best one was selected based on its ability to provide the most precise results.

1.1 Preparation of database

For circular specimen, database of 125 specimen is collected through different studies (Al-Kamaki, Al-Mahaidi, & Bennetts, 2015; H. S. Al-Nimry, Ghanem, & Materials, 2017; Benzaid & Mesbah, 2013; Hussain, Yaqub, Mortazavi, Ehsan, & Uzair, 2022; Siddiqui et al., 2014; Xu, 2022; Yaqub, Bailey, & Materials, 2011)During the database development process, 10 parameters were systematically recorded from each experimental program and subsequently utilized as inputs for the neural network. These parameters encompassed the diameter of columns (mm), column height (mm), concrete's initial compressive strength (MPa), steel's initial tensile strength (MPa), longitudinal reinforcement ratio (As/Ag %), temperature of fire (°C), fire exposure time (Minutes), number of layers of CFRP (Count), thickness of CFRP (mm), and tensile E-modulus of CFRP (GPa). Additionally, the axial load capacity (kN) of columns was recorded as the output variable for the proposed neural network. Similarly for Square columns The database of 143 samples is collected through 9 different studies (Chinthapalli & Agarwal, 2020; Jin, Chen, Wang, & Du, 2020; VKR Kodur, Bisby, & Green, 2004; Venkatesh Kodur, Hibner, & Agrawal, 2017; Lie, 1989; Lin & Tsay, 1990; Moghtadernejad et al., 2021; Tao & Yu, 2008; Yeo, 2013). During the development of database 12 parameters are considered with column dia replaced with Length of Columns (mm), Width of Columns (mm) and Corner Radius (mm). rest all parameters are same as circular columns

1.2 Structure of Neural networks:

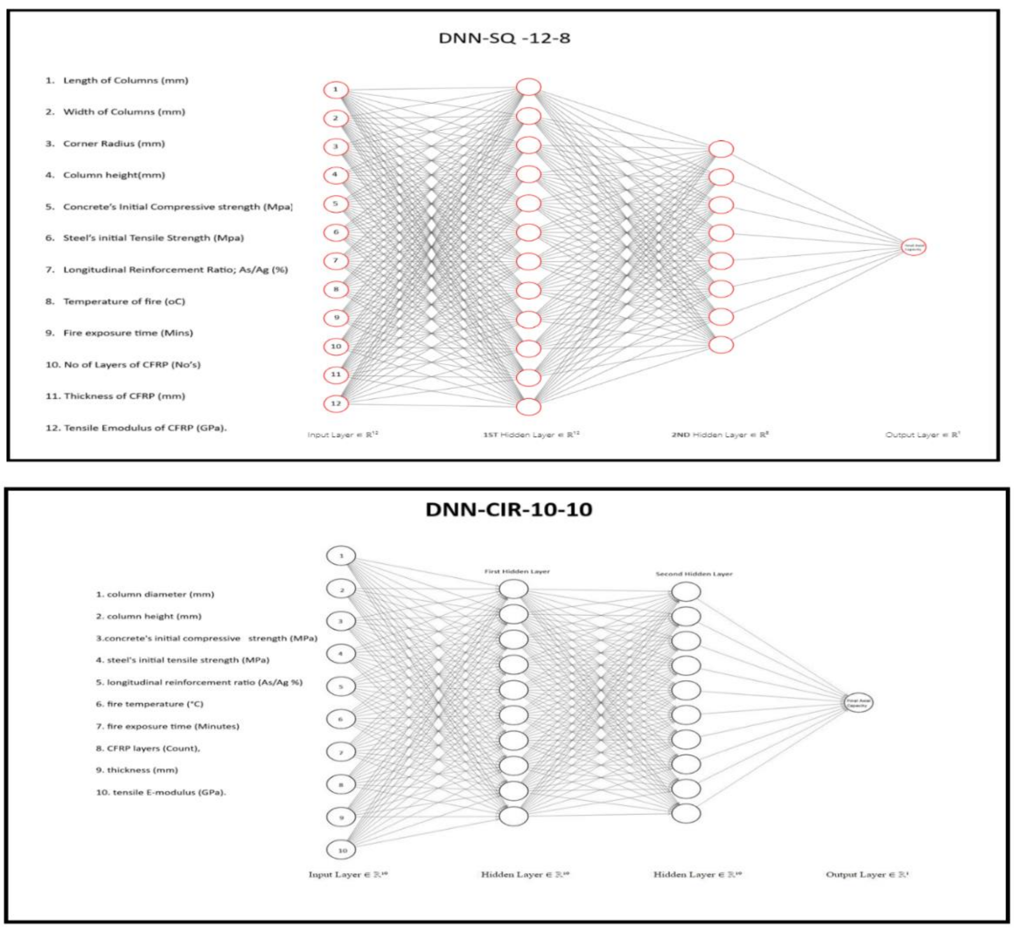

Figure 2 Architecture of both DNN Models

The DNN model made for Rectangular column has 2 hidden layers with 12 neurons in first layer and 8 neurons in second layer. The dnn model made for cicular column has two hidden layers and 10 neurons in each layer

1.3 Features of most optimum model

For DNN-Sq-12-8, Correlation factor (R) of training, validation, Testing and overall is found out to be 0.99967, 0.99972, 0.99623 and 0.99946 respectively.

The correlation factor (R) values of Training, Validation, Testing, and overall R value for DNN -Cir-10-10 are displayed. The correlation factors for training, validation, testing, and overall are determined to be 0.99926, 0.99805, 0.99748, and 0.99852 respectively.

DNN-Sq-12-8 has value of overall correlation factor (R) which is 0.99946 and has the value of RMSE, MSE and MAE having magnitude 0.404, 0.1634 and 10.337% respectively

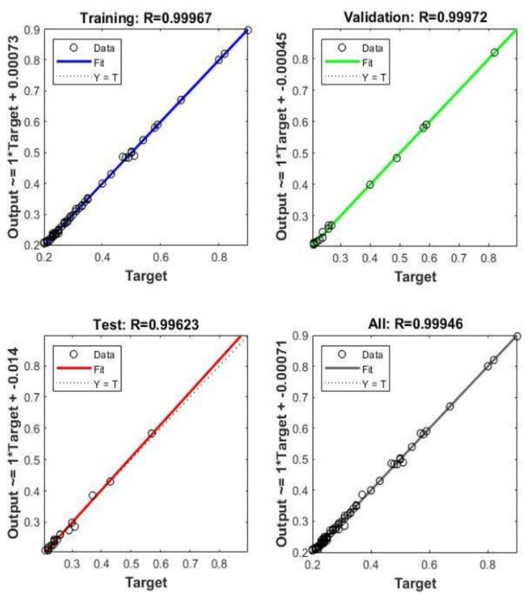

Figure 3a

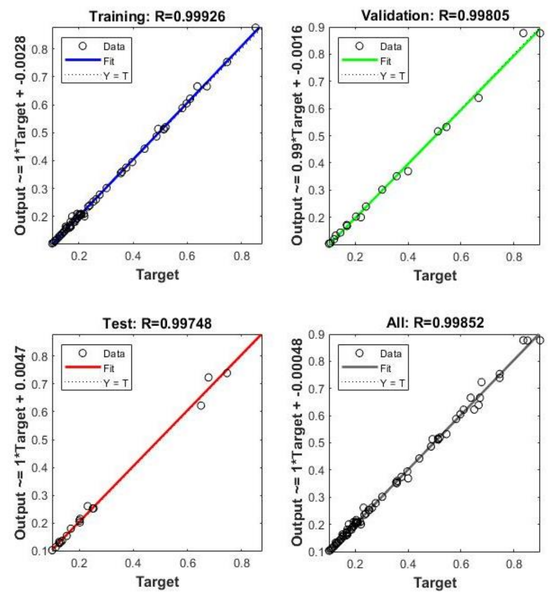

Figure 3b

Figure 3 Training, Validation, Testing and Overal Correlation Factor for (a) DNN-Sq-12-8 and (b) DNN-Cir-10-10

3. Results And Discussion

The purpose of this investigation is to observe the effect of cross-sectional shape on the axial capacity of fire damaged and CFRP repaired circular and square reinforced Concrete (RC) columns. In sections Below, it is presented how different shapes of concrete columns impact the final axial capacity of fire damaged columns repaired with CFRP sheets.

Effect of fire and CFRP wraps on the circular and square concrete columns:

In this section of the study impact of fire on the axial capacit of RC concrete columns is presented and the effect of CFRP confinement on the damaged strength in also potrayed for square and circular concrete columns. The study was designed keeping the Crossectional area of both columns (square and circular) equal having value of 40000 mm2. Moreover, Square columns were 200 by 200 mm and other parameters were kept as follows: Corner Radius (R) = 0 mm, Specimen Height (H) = 1000 mm, Compressive Strength of Concrete (Fc) = 53 MPa, Tensile Strngth of steel = 553 MPa, Reinforcment ration (As/Ag) = 1.5 %, Fire Temprature = 300 oC Fire Exposure Time = 180 min, Number of CFRP layers = 1, CFRP thickess = 0.117

mm and Tensile E-modulus of CFRP = 240 GPa. On the other hand for circular columns the diameter was kept equal to 225 mm, rest everything was same as for rectangular columns. Since the crossectional area and all other parameters of both types of columns were kept constant so it would be an excellent prediction of how fire damage and CFRP confinement differes on both columns having different crossectional shapes.

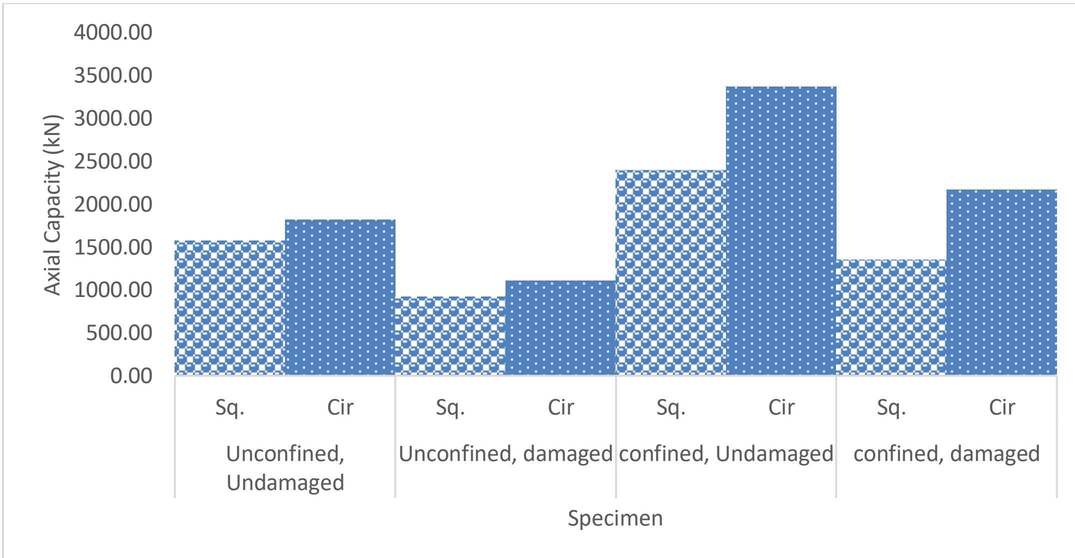

Figure 4 Effect of fire and CFRP wraps on the circular and square concrete columns

There are four cases (Unconfined & Undamaged, Unconfined & damaged, confined & Undamaged and confined & damaged) as shown in Fig 4. From the results following can be deduced.

1. When columns were damaged with fire at 300 oC for 180 mins the axial capacity of circular columns dropped by 39% meanwhile 41% dip was observed in case of square columns.
2. Under almost same geometrical conditions, when undamaged circular column was confined with 1 layer of CFRP, the axial capacity was increased by 82% meanwhile in case of square the increment was 52%. The results indicate that the CFRP confinement is more effective on circular columns.
3. As far as repairing fire damaged columns with CFRP composites, same trend is observed as in repairing undamaged columns. After confinement with 1 CFRP layer the axial capacity of circular columns increased by 95.8% while an increment of 46.7% was observed in circular columns.

Variation in axial capacity of circular and square RC columns against the Compressive strength of Concrete: To observe more closely the variation in repaired strength of columns having different shapes after being confined with CFRP, another parametric study was designed in which the initial compressive strength of concrete (Fc) was varied from 20 to 65 MPa and variation in axial load capacity of fire damaged and CFRP repaired circular and square columns is observed. Input parameters of square columns are kept as follows: L x W = 200 x 200 mm, Corner Radius (R) = 0 mm, Specimen Height (H) = 1000 mm, Tensile Strength of steel = 550 MPa, Reinforcment ration (As/Ag) = 1.6 %, Fire Temprature = 300 oC Fire Exposure Time = 120 min, Number of CFRP layers = 1, CFRP thickess = 0.117 mm and Tensile E-modulus of CFRP = 240 GPa. For cicular columns every thing was similar and the diameter of columns was kept as 225 mm giving the same cross-sectional area as the square columns.
As shown in Fig.5, the CFRP confinement is more effective in circular columns than that in square columns. When the columns having concrete compressive strength of 20 MPa were repaired with 1 layer of CFRP, the regain in circular column was 29% higher than that in square columns. Moreover, it can also be deduced that as the initial compressive strength of concrete was increased, the repaired strength kept on increasing. But the confinement has been more effective on circular columns comparatively.

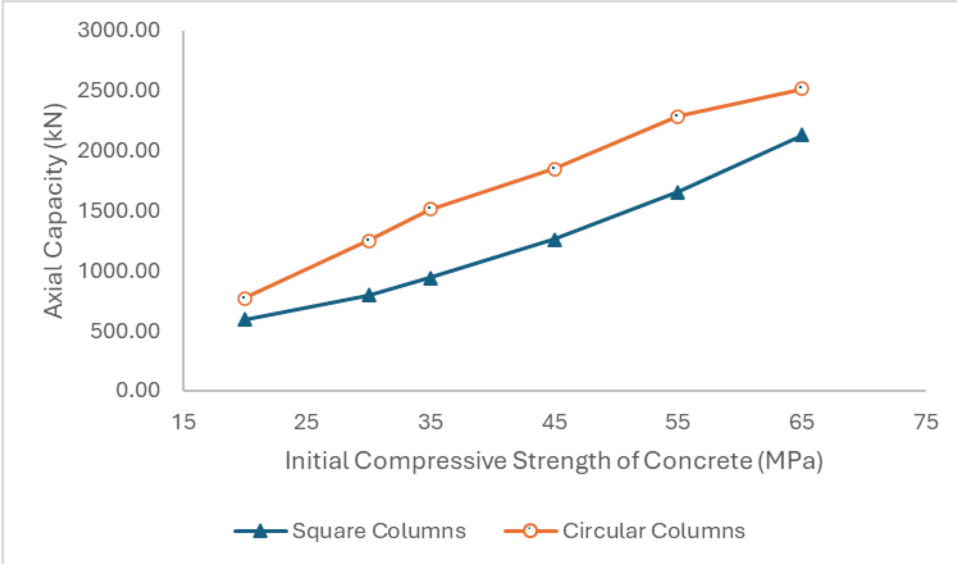

Figure 5 Effect of Compressive strength of Concrete

3.1 Impact of Corner radius on axial capacity of square/rectangular columns

In order to present the effect of different corner radius (R) on the repaired axial strength of square/rectangular RC columns, another paramteric study is designed. The Corner radius is varied from 0 to 40mm. Moreover, Compressive strength of concrete (Fc) was changed 20 45 MPa to include different types of columns in the study. All other inputs parameters were kept as follows: L x W = 200 x 200 mm, Height (H) = 1000 mm, Tensile Strength of steel = 550 MPa, Reinforcment ration (As/Ag) = 1.6 %, Fire Temprature = 300 oC Fire Exposure Time = 120 min, Number of CFRP layers = 1, CFRP thickess = 0.117 mm and Tensile E-modulus of CFRP = 240 GPa.

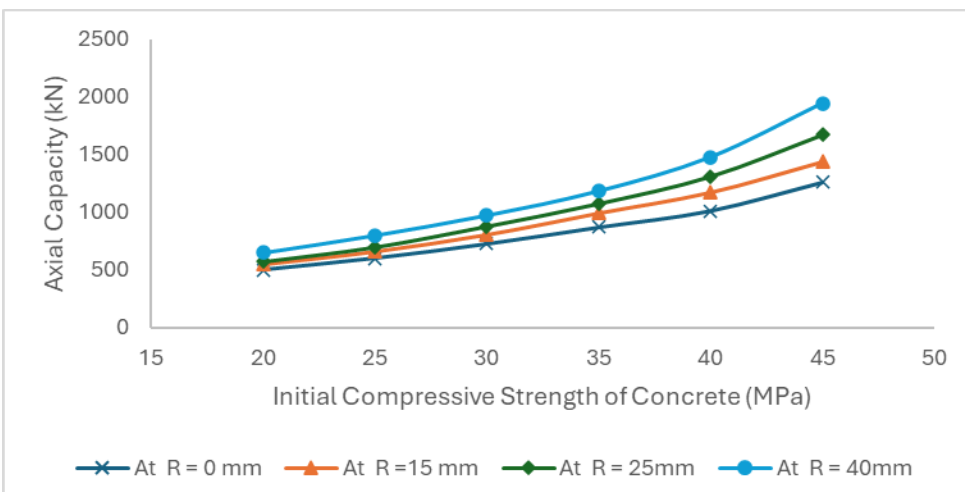

Figure 6 predicting the Impact of Corner radius on axial capacity of square/rectangular columns

As presented in Fig. 6, Specimens having the Corner radius of 40 mm performed much better than the other specimens with R value varying from 0 to 40 mm. At 45 MPa the repaired axial capacity of columns having corner radius of 45 mm was almost 35% higher than the specimen with zero corner radius.

4. Conclusion

The purpose of this study was prepare artifical neural network models to highlight the impact of cross sectional shape of columns on the axial capacity of fire damaged and CFRP repaired columns. The following points can be deduced from this investigation.

1. Models DNN-Sq-12-8 & DNN-Cir-10-10 haing R value of 0.99946 and 0.99852 respectively proved to be the most accurate models.
2. CFRP confinement is more effective on circular columns than the square/rectangular columns. When fire damaged circular and square columns having similar geometrical, damage and confinement parameters were repaired, the axial capacity circular columns was 29% more than the squae columns.
3. The corner radius in case of square columns also plays an important role. Higher the corner radius lesser would be the knife actions resulting in better confinment. For instance, columns having corner radius of 40mm had the repaired strength 35% higher than the specimen with 0mm corner radius.

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