ISSN: 0975-833X

Available online at http://www.journalcra.com

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

International Journal of Current Research
Vol. 13, Issue, 10, pp.19008-19013, October, 2021

DOI: https://doi.org/10.24941/ijcr.42034.10.2021

RESEARCH ARTICLE

VALIDATION OF EXPERIMENTAL RESULTS OF GFRP STRENGTHENED CORROSION DAMAGED RC COLUMNS WITH EXISTING MODELS

[1]Dhevasenaa P.R. and [2]Jayaaruna, S.S.

Assistant Professor of Civil Engineering, Government College of Engineering Srirangam

ARTICLE INFO

Article History:
Received 19th July, 2021
Received in revised form
24th August, 2021
Accepted 19th September, 2021
Published online 30th October, 2021

Key Words:

Corrosion, Ductility, GFRP, Wrap

Corresponding author:
Dhevasenaa P.R.

ABSTRACT

This paper presents the validation of experimental investigation on Glass Fibre Reinforced Polymer (GFRP) strengthened high strength concrete columns. A total of 14 test specimens of 150mm diameter and height of 600 mm were cast and tested. The level of corrosion-damage was 0%, 15% and 30%, glass fibre reinforced polymer wraps with different configurations such as Chopped Strand Mat (CSM), Uni Directional Cloth (UDC) and Woven Roving (WR) each of 3 mm and 5 mm thickness are used in this study. All the test specimens were tested under monotonic loading up to failure, in a loading frame of capacity 2000 kN. The ultimate stress and ultimate strain levels reached by the FRP confined concrete columns have been validated with the existing models. The validation results concluded that Xia and Wu (2000), Fardis and Khalili (1981) and Kono et al. (1998) showed reasonable agreement with the experimental ultimate compressive stresses and strains.

Citation: Dhevasenaa P.R. and Jayaaruna, S.S. "Validation of Experimental Results of GFRP Strengthened Corrosion Damaged RC Columns with Existing Models*", 2021. International Journal of Current Research, 13, (10), 19008-19013.*

INTRODUCTION

The repair and strengthening of structural concrete members, is conceivably one of the most significant problems in civil engineering applications. The structural strengthening may be required in situations where additional strength may be needed to allow for higher loads to be placed on the structure; when the structure has to resist loads that were not anticipated in the original design or additional strength may be needed due to deficiency in the structure's ability to carry the original design loads. The deficit may well be the result of deterioration, structural damage or errors in original design or construction. Fibre Reinforced Polymer (FRP) is relatively a innovative technology in advanced composite materials. FRP exhibit several improved properties such as high strength-weight ratio, high stiffness-weight ratio, flexibility in design, high fatigue strength, ease of transportation and handling, low maintenance cost and good corrosion resistance. They have been extensively used in aerospace, automotive and other fields. Based on these properties this study has been undertaken for evaluating the performance of Glass Fibre Reinforced Polymer (GFRP) for strengthening the corroded high strength concrete columns. Reinforced concrete columns can be strengthened using FRP composites by wrapping, filament winding or prefabricated shell jacketing. In-situ FRP wrapping is the most extensively used technique for strengthening columns.

Unidirectional fibre sheets or woven fabric sheets are impregnated with polymer resins and wrapped around columns in a wet lay-up process. The column can be fully wrapped with FRP sheets, partially wrapped with FRP strips in a continuous spiral or partially wrapped with discrete rings. The filament winding technique uses continuous fibre strands instead of sheets/strips so that winding can be processed automatically using a computer controlled winding machine. Lateral confinement using fiber-reinforced polymers (FRPs) would enhance the ultimate axial load, strain and ductility of structural compression members effectively. Over the past decade, the FRP composites bring into play for the retrofitting, strengthening, and ductility enhancement of RC compression members. American Concrete Institute (ACI) published report No. 440 in the year 2002, containing guidelines for the use of FRP as internal and external reinforcement in concrete construction. The committee was chaired by Sami H. Rizkalla and produced two separate reports, ACI 440.1R for internal FRP reinforcement and ACI 440.2R for externally bonded FRP reinforcement. The committee report No. 440.2R included comprehensive guidelines for strengthening in flexure, shear, axial tension and axial compression. The report also covered material properties of FRP and construction requirements related to installation, inspection and maintenance. The report presented equations for estimating the design strength of FRP confined reinforced concrete columns in compression based on the concrete confinement equation proposed by Mander et al. (1988). Many theoretical models have been published for estimating the ultimate compressive stress and ultimate compressive strain levels likely to be reached by a column. The experimental results were compared with the predictions of theoretical models to ascertain the extent to which the experimental values agree with the models. The models used for predicting the compressive strength of FRP confined concrete cylinders were listed below. The strength of reinforcing steel is added to the estimated compressive strength to get the total theoretical prediction.

Fardis and Khalili (1981) Model

Two sets of empirical models were proposed by Fardis and Khalili (1981) for predicting the ultimate compressive stresses and strain of FRP confined concrete.

These models were modifications of the models proposed by Richart et al. (1928) and Newman and Newman (1972) confined concrete. The Fardis and Khalili (1981) equations for compressive strength of FRP confined concrete are,

$$\frac{f'_{cc}}{f'_{co}} = 1 + 4.1\left(\frac{2\mathrm{f}_{fu}nt}{f'_{co}D}\right) \qquad \text{(Eq.1)}$$

and

$$\frac{f'_{cc}}{f'_{co}} = 1 + 3.7\left(\frac{2\mathrm{f}_{fu}nt}{f'_{co}D}\right)^{0.86} \qquad \text{(Eq.2)}$$

The equation for estimating the peak compressive strain in confined concrete was proposed as.

$$\varepsilon_{cc} = \varepsilon_{co} + 0.001\left(\frac{E_f nt}{f'_{co}D}\right)\mathrm{n} \qquad \text{(Eq.3)}$$

The researchers put forth an equation for estimating the complete stress-strain behaviour of FRP confined concrete as,

$$f_c = \frac{E_{co}\varepsilon_c}{1 + \left(\frac{E_{co}}{f'_{cc}} - \frac{1}{\varepsilon_{cc}}\right)} \qquad \text{(Eq.4)}$$

Mander et al. (1988) Model

This model was originally proposed for concrete confined using steel tubes. But, the some model was able to predict the ultimate stress values of GFRP confined concrete also. The American Concrete Institute (ACI) have taken this model as the basis for proposing an equation to predict the compressive strength of FRP confined reinforced concrete columns (ACI 440.2R, 2002). The model proposed by Mander et al. (1988) is,

$$f'_{cc} = f'_{co}\left[2.25\sqrt{1 + 7.9\frac{f_l}{f'_{co}}} - 2\frac{f_l}{f'_{co}} - 1.25\right] \qquad \text{(Eq.5)}$$

The value of confining pressure, f_l can be estimated using the expression,

$$f_l = \frac{2nt\varepsilon_{fe}E_f}{D} \qquad \text{(Eq.6)}$$

Saadatmanesh et al. (1994) Model: This model was a modification to the model proposed by Mander et al. (1988). The model proposed by Saadatmanesh et al. for compressive strength of FRP confined concrete was,

$$f'_{cc} = f'_{co}\left[2.254\sqrt{1 + 7.94\frac{f_l}{f'_{co}}} - 2\frac{f_l}{f'_{co}} - 1.254\right] \qquad \text{(Eq.7)}$$

In the above equation, the value of the confining pressure f_l should be estimated using equation 6.6.

Miyauchi et al. (1997) Model: Miyauchi et al. (1997) proposed the following model for estimating the compressive strength of FRP confined concrete column,

$$\frac{f'_{cc}}{f'_{co}} = 1 + 4.1\mathrm{k}_u\left(\frac{2f_{fu}nt}{f'_{co}D}\right) \quad \text{(Eq.8)}$$

The values of k_u was calibrated as 0.85 from their experimental results. The ultimate axial strain values could be estimated using the expressions,

$$\frac{\varepsilon_{cc}}{\varepsilon_{co}} = 1 + 10.6\left(\frac{2f_{fu}nt}{f'_{co}D}\right)^{0.373} \quad for \quad f'_{co} = 30MPa \quad \text{(Eq.9)}$$

$$\frac{\varepsilon_{cc}}{\varepsilon_{co}} = 1 + 10.5\left(\frac{2f_{fu}nt}{f'_{co}D}\right)^{0.525} \quad for \quad f'_{co} = 50MPa \quad \text{(Eq.10)}$$

Kono et al. (1998) Model: The models proposed by Kono et al. (1998) for ultimate compressive stress and strain were,

$$\frac{f'_{cc}}{f'_{co}} = 1 + 0.572\frac{2f_{fu}nt}{D} \quad \text{(Eq.11)}$$

$$\frac{\varepsilon_{cc}}{\varepsilon_{co}} = 1 + 0.280\frac{2f_{fu}nt}{D} \quad \text{(Eq.12)}$$

Saaman et al. (1998) Model: The models proposed by Saaman et al. (1998) for ultimate compressive stress and strain values were,

$$\mathrm{f}'_{\mathrm{cc}} = \mathrm{f}'_{\mathrm{co}} + 6.0\left(\frac{2\mathrm{f}_{\mathrm{fu}}\mathrm{nt}}{\mathrm{D}}\right)^{0.7} \quad \text{(Eq.13)}$$

$$\varepsilon_{cc} = \frac{f'_{cc} - f_o}{E_2} \quad \text{(Eq.14)}$$

where, f_o can be calculated using the expression,

$$f_o = 0.872f'_{co} + 0.371\frac{2f_u nt}{D} + 6.258 \quad \text{(Eq.15)}$$

and E_2 can be estimated using the expression,

$$E_2 = 245.61{f'_{co}}^{0.2} + 1.3456\frac{E_f nt}{D} \quad \text{(Eq.16)}$$

Tautanji (1999) Model: The models proposed by Tautanji (1999) for estimating the ultimate compressive stress and strain values of FRP confined concrete were,

$$\frac{f'_{cc}}{f'_{co}} = 1 + 3.5\left(\frac{2f_{fu}nt}{f'_{co}D}\right)^{0.85} \quad \text{(Eq.17)}$$

$$\frac{\varepsilon_{\mathrm{cc}}}{\varepsilon_{\mathrm{co}}} = 1 + \left(310.57\frac{\mathrm{f}_{\mathrm{fu}}}{\mathrm{E}_{\mathrm{f}}} + 1.9\right)\left(\frac{\mathrm{f}'_{\mathrm{cc}}}{\mathrm{f}'_{\mathrm{co}}} - 1\right) \quad \text{(Eq.18)}$$

Saafi et al. (1999) Model: This model is modification of the one proposed by Tautanji et al. (1999), with slight variations to the numerical parameters.

$$\frac{f'_{cc}}{f'_{co}} = 1 + 2.2\left(\frac{2f_{fu}nt}{f'_{co}D}\right)^{0.84} \qquad \text{(Eq.19)}$$

$$\frac{\varepsilon_{cc}}{\varepsilon_{co}} = 1 + \left(537\frac{f_{fu}}{E_f} + 2.6\right)\left(\frac{f'_{cc}}{f'_{co}} - 1\right) \qquad \text{(Eq.20)}$$

Xiao and Wu (2000) Model: The model proposed by Xia and Wu was based on empirical calibrations carried out on the experimental results obtained by them for FRP confined concrete columns. The ultimate compressive stress and strain were represented by,

$$\frac{f'_{cc}}{f'_{co}} = 1.1 + \left(4.1 - 0.75\frac{f'^{2}_{co}}{E_l}\right)\frac{2f_{fu}nt}{f'_{co}D} \qquad \text{(Eq.21)}$$

$$\varepsilon_{cc} = \frac{\varepsilon_{fu} - 0.0005}{7\left(\frac{f'_{co}}{E_l}\right)^{0.8}} \qquad \text{(Eq.22)}$$

and E_l, the confinement modulus, could be calculated using the expression,

$$E_l = \frac{2E_f nt}{D} \qquad \text{(Eq.23)}$$

ACI 440.2R (2002) Model for FRP Confined RC Column: The equation proposed by ACI 440.2R were meant for a conservative estimate of the compressive strength of reinforced concrete columns, incorporating many partial safety factors. The basic equation for computing the compressive strength of reinforced concrete columns having internal circular steel ties and wrapped with FRP composite was,

$$\varphi P_n = 0.80\varphi\left[0.85\psi_f f'_{cc}\left(A_g - A_{st}\right) + f_y A_{st}\right] \qquad \text{(Eq.24)}$$

where, the compressive strength of FRP confined concrete (f'_{cc}) can be estimated using the model proposed by Mander et al. (1988). The value of the strength reduction factor (φ) is 0.70 for compression members with circular ties and 0.75 compression members with spiral ties.

Estimating Compressive Strength of Confined HSC Columns: The equation proposed by ACI 440.2R (2002) for compressive strength of FRP confined concrete columns incorporated several partial safety factors, thus making the predictions suitable only for construction purposes.

The results obtained from destructive experiments are the maximum permissible values for confined concrete which need not have any partial safety factor. Hence, the following equation was proposed for estimating the ultimate compressive stress permissible in a reinforced concrete column,

$$f'_{crc} = f'_{cc}\left(\frac{A_g - A_{st}}{A_g}\right) + f_y\left(\frac{A_{st}}{A_g}\right) \qquad \text{(Eq.25)}$$

Implementation of the Models and Comparison: The models were implemented in C++ programming language for the prediction of ultimate stress and strain values. The computer program aided in the fast prediction of results for all the columns considered in the present study.

Comparison of Model Predictions with Experimental Results: The Root Mean Squared Percentage Error (RMSPE) values of experimental results and model predictions are presented in the last rows of both tables. Figs. 1 to 6 display the comparison of experimental with predictions from models.

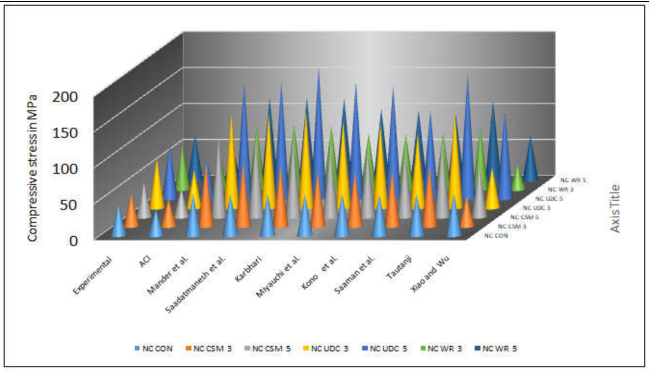

Fig. 1. Model Prediction and Experimental Values of Ultimate Stress for Reference Columns

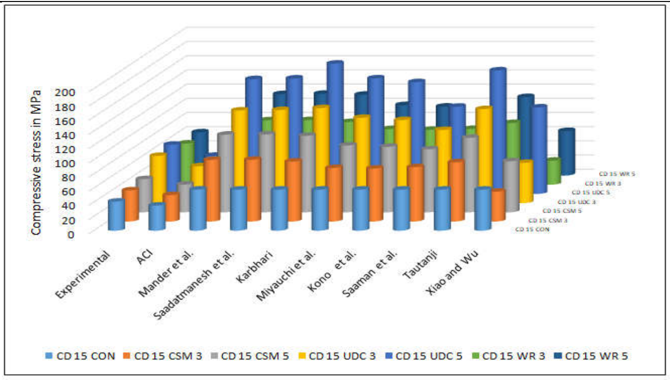

Fig.2. Model Prediction and Experimental Values of Ultimate Stress for 15% Corroded columns

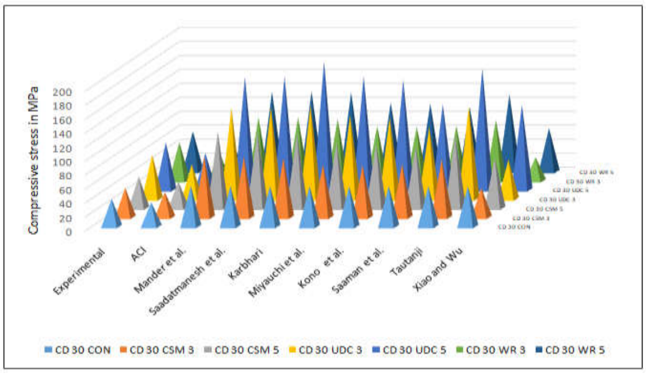

Fig. 3. Model Prediction and Experimental Values of Ultimate Stress for 30% Corroded columns

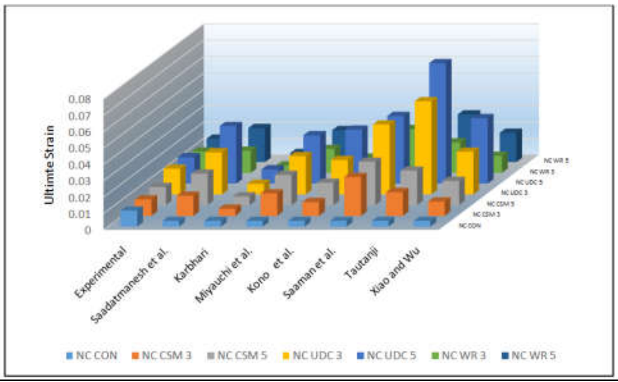

Fig. 4. Model Prediction and Experimental Values of Ultimate Strain for Reference Columns

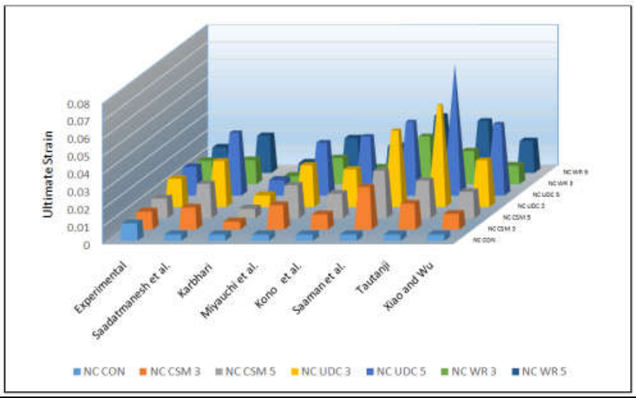

Fig. 5. Model Prediction and Experimental Values of Ultimate Strain for 15% Corroded columns

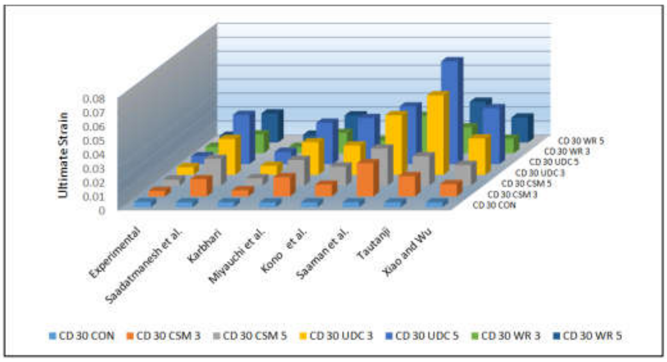

Fig. 6. Model Prediction and Experimental Values of Ultimate Strain for 30% Corroded columns

Conclusion

GFRP wrapped corrosion-damaged concrete columns show a considerable enhancement in the load carrying capacity, deflection and ductility than the control concrete columns. The ultimate stresses predicted by the models proposed by ACI440.2R closely agreed with the experimental results and Xia and Wu (2000) showed reasonable agreement with the experimental ultimate compressive stresses. The ultimate axial strain values predicted by the models showed deviation from the experimental results. The prediction of ultimate axial strains from the models of Fardis and Khalili (1981) and Kono et al. (1998) were in reasonable agreement with the experimental results. The reason for the deviations of the experimental results and model predictions is that the models did not consider slenderness ratio as a parameter.

REFERENCES

ACI, 440.2R, 2002. Guide for the Design and Construction of Externally Bonded FRP Systems for strengthening Concrete Structures, *American Concrete Institute*, Detroit, Michigan, USA, 1-45.

Fardis, M.N., Khalili, H.H. 1982. FRP-encased concrete as a structural material. *Mag. Concr. Res.,* 34, 191–202.

Hadi, M. N. 2007. Behaviour of FRP strengthened concrete columns under eccentric compression loading. *Composite Structures*, *771*, 92-9

Kono, S., Inazumi, M., & Kaku, T. 1998. January. Evaluation of confining effects of CFRP sheets on reinforced concrete members. In *Second International Conference on Composites in InfrastructureNational Science Foundation* Vol. 1

Mander, J.B., Priestley, M.J., Park, R. Theoretical stress-strain model for confined concrete. J. Struct. Eng. 1988, 114, 1804–1826.

Miyauchi, K. Estimation of strengthening effects with carbon fiber sheet for concrete column. In Proceedings of the 3rd International Symposium on Non-Metallic FRP Reinforcement for Concrete Structures, Sapporo, Japan, 14–16 October 1997; pp. 217–224.

Saadatmanesh, H., Ehsani, M. R., & Li, M. W. 1994. Strength and ductility of concrete columns externally reinforced with fiber composite straps. *Structural Journal*, *91*4, 434-447.

Saafi, M., Toutanji, H.A., Li, Z. 1999. Behavior of concrete columns confined with fiber reinforced polymer tubes. *Mater. J.* 96, 500–509.

Samaan, M., Mirmiran, A., & Shahawy, M. 1998. Model of concrete confined by fiber composites. *Journal of structural engineering*, *124*9, 1025-1031.

Toutanji, H. Stress-strain characteristics of concrete columns externally confined with advanced fiber composite sheets. Mater. J. 1999, 96, 397–404.

Xiao, Y., & Wu, H. 2000. Compressive behavior of concrete confined by carbon fiber composite jackets. *Journal of materials in civil engineering*, *12*2, 139-146.

****