Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 51(6) (2020)355-358
DOI: 10.22060/ceej.2018.14493.5672

Strengthening Optimization of RC Columns with Rectangular Section by FRP Wrapping

K. Nadimi Shahraki, M. Reisi*

Department of Civil Engineering, Khomeinishahr Branch, Islamic Azad University, Isfahan, Iran

ABSTRACT: Wrapping reinforced concrete (RC) column with FRP sheets improves compressive strength of concrete. Since stress-strain curve of concrete confined with FRP is different from stress-strain curve of normal concrete, equations presented by codes for design and analysis of normal (unstrengthened) RC column and based on stress-strain curve of normal concrete cannot be used for design and analysis of columns strengthen with FRP. In this research, first by using stress-strain curve of confined concrete presented by researchers and ACI code, an algorithm was designed to determine axial and flexural capacity of strengthened column and implemented in Visual C# environment. Verification of this work was investigated and confirmed by comparing it with experimental results. The programming was developed in a way that it could be used to optimize the design. Thus, by specifying required information including cross sectional dimensions, number and diameter of rebars, applied axial load and bending moment on column, FRP sheet properties and price, the performed programming can determine which type of FRP, if used, while providing the required flexural and axial capacity , has also the minimum price

Review History:

Received: 5/24/2018
Revised: 7/28/2018
Accepted: 7/29/2018
Available Online: 8/14/2018

Keywords:

Confined Concrete
FRP sheets
Stress-Strain curve
Optimization

1. INTRODUCTION

Some reinforced concrete (RC) structures, due to variety of reasons such as improper implementation of concrete, change in structure use or design codes, require strengthening. Since 1980s, because of excellent properties of FRP composites including high tensile strength to weight ratio, suitable corrosion resistance and durability, ease of transportation and application, they have been widely used. Wrapping column with FRP sheets confine concrete core and therefore enhances concrete compressive strength and ductility.

Since stress-strain curve of concrete strengthened with FRP is different from stress-strain curve of normal concrete, relations proposed by codes and based on stress-strain curve of normal concrete cannot be used for analysis and design of column strengthened with FRP. Many attempts have been started in experimental tests and theoretical studies to present a model for stress-strain curve of concrete confined with FRP, and have been continued until now. Among these models, models which have presented stress-strain curve for columns with circular and rectangular cross-sections can be referred to Mirmiran et al. [1] in 1997, Campione and Miraglia [2] in 2003, Lam and Teng [3] in 2003 and model proposed by ACI 440 [4] in 2008. In the present study, these four models are used for determination of flexural and axial capacity of column strengthened with FRP.

*Corresponding author's email: mreisi@iaukhsh.ac.ir

2. RESEARCH METHODOLOGY AND OBTAINED RESULTS

2.1. Determination of axial and flexural capacity of strengthened RC column with rectangular section with regard to stress-strain curve

For determination of flexural and axial capacity of a rectangular section strengthened with FRP, first, based on stress-strain curve of concrete confined with FRF (which is presented by the researchers and ACI code), and equilibrium and compatibility equations, an algorithm was designed. Figures 1 and 2 show stress and strain distribution in a RC rectangular section at ultimate failure state. In Figure 1, axial

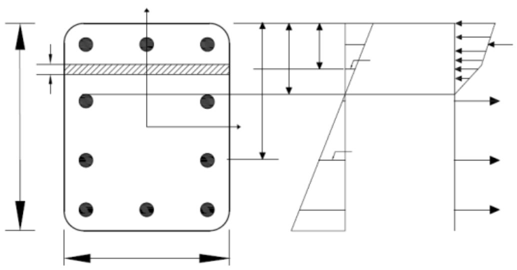

Fig. 1. Stress-strain distribution at section of RC column confined with FRP under axial force and unidirectional

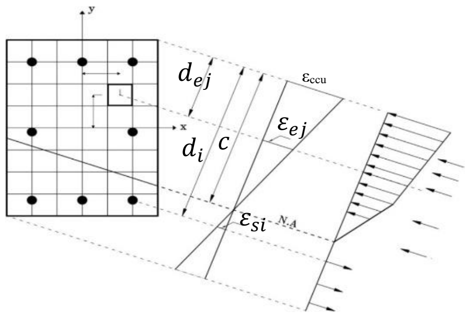

Fig. 2. Stress-strain distribution at section of RC column confined with FRP under axial force and bidirectional bending moment

force and uniaxial bending moment and in Figure 2, axial force and biaxial bending moment are applied on section. As it is observed, in calculation of cross section forces in columns under uniaxial bending moment, horizontal strip element and for column under biaxial bending moment, square element is used.

According to Figures 1 and 2, by writing similarity equation in strain diagram, strain of rebars can be obtained from Equation 1 and by using Equation 2, stress of rebars can be determined. Strain of each element of concrete section can be determined by Equation 3; also with respect to stress distribution at section, according to Figure 1, Equations 4 and 5 can be written for section under uniaxial bending moment and according Figure 2, Equations 6 to 8 can be written for section under biaxial bending moment.

$$\frac{\varepsilon_{ccu}}{\varepsilon_{si}} = \frac{c}{c-d_i} \rightarrow \varepsilon_{si} = \varepsilon_{ccu} \times \frac{c-d_i}{c} \quad (1)$$

$$f_{si} = E_s \times \varepsilon_{si} \leq f_{yi} \quad (2)$$

$$\frac{\varepsilon_{ccu}}{\varepsilon_{ej}} = \frac{c}{c-d_{ej}} \rightarrow \varepsilon_{ej} = \varepsilon_{ccu} \times \frac{c-d_{ej}}{c} \quad (3)$$

$$P_n = \sum_{i=1}^{Nor} F_{si} + \sum_{j=1}^{Noe} F_{ej} = \sum_{i=1}^{Nor} f_{si} A_{si} + \sum_{j=1}^{Noe} f_{ej}\, b'\, \Delta y \quad (4)$$

$$M_{nx} = \sum_{i=1}^{Nor} f_{si} A_{si}\, y_{si} + \sum_{j=1}^{Noe} f_{ej}\, b'\, \Delta y\, y_{ej} \quad (5)$$

$$P_n = \sum_{i=1}^{Nor} F_{si} + \sum_{j=1}^{Noe} F_{ej} = \sum_{i=1}^{Nor} f_{si} A_{si} + \sum_{j=1}^{Noe} f_{cj}\, \Delta x\, \Delta y \quad (6)$$

$$M_{nx} = \sum_{i=1}^{Noe} f_{si} A_{si}\, y_{si} + \sum_{j=1}^{Noe} f_{cj}\, \Delta x\, \Delta y\, y_{ej} \quad (7)$$

$$M_{ny} = \sum_{i=1}^{Nor} f_{si} A_{si}\, x_{si} + \sum_{j=1}^{Noe} f_{ej}\, \Delta x\, \Delta y\, x_{ej} \quad (8)$$

With respect to the above presented equations, an algorithm was designed to determine axial and flexural capacity of column strengthened with FRP and this algorithm was programed and implemented in Visual C# environment. Stress-strain curves for confined concrete proposed by Mirmiran [1], Campione and Miraglia [2], Lam and Teng [3] and ACI 440 [4] was introduced to the program in a way that the performed program is able to calculate axial and bending capacity of column for each of abovementioned models for different amounts of neutral axis height (c). Meanwhile, interaction curve for axial-bending moment $(M_n - P_n)$ can be plotted.

To verify algorithm and the performed program for column with rectangular section strengthened with FRP under axial force and uniaxial bending moment, experimental tests done by Lacobucci et al. [5] and Bousias et al. [6] were used and for column under axial force and biaxial bending moment, experimental tests done by Youcef et al. [7] , El Sayed and El Maaddawy [8] and Punurai et al. [9] were used. Results obtained from verification showed that outputs obtained from the performed programming were in good agreement with experimental results.

3. OPTIMIZATION OF STRENGTHENING COLUMN

In strengthening optimization column with FRP, always this goal is pursued that among available FRP sheet types, a type of sheet is chosen which if it used for strengthening, in addition to providing required flexural and axial capacity, has the minimum price. In this research, an algorithm was developed to determine demand to capacity ratio (D/C) of column strengthened with FRP under axial force and bending moment (uniaxial and biaxial) and its programming was performed in visual C# environment. The developed program is capable to design layer number of FRP sheets which should be used for strengthening columns; then, the program was developed in a way that it can be used to optimize strengthening of design. In this way, by determining section dimensions and available amount of reinforcement along with axial load and bending moment on column and also by introducing available FRP sheet properties with their prices, the performed program can determine which type of FRP, if used, while providing the required flexural and axial capacity, has also minimum price.

4. CONCLUSION AND RESULT

The aim of the present research is to optimize strengthening design RC column with FRP sheets by wrapping. To this end, first an algorithm based on stress-strain curve of confined concrete (which was proposed by researches and ACI code) was developed and equilibrium and compatibility equations were used to determine axial and flexural (uniaxial and biaxial) capacity of strengthened column. Obtained results showed that the used method and the performed programming is able to be used to predict flexural and axial capacity of column strengthened with FRP and to optimize strengthening design.

References

[1]A. Mirmiran, M. Shahawy, Behavior of Concrete Columns Confined by Fiber Composites, Journal of Structural Engineering, ASCE, 123(5) (1997) 583-590.

[2]G. Campione, N. Miraglia, Strength and Strain Capacities of Concrete Compression Members Reinforced with FRP, Journal of Cement & Concrete, 25 (2003) 31-41.

[3]L. Lam, J.G. Teng, Design-Oriented Stress-Strain Model

for FRP-Confined Concrete, Journal of Construction and Building Materials, (17) (2003) 471-489.

[4]A.C. Institution, ACI Committee 440.2R-08,"Guide for The Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures., in: ACI Committee 440.2R-08,, ACI, First Printing., ACI, 2008.

[5]R.D. Lacobucci, S.A. Sheikh, O. Bayrak, Retrofit of Square Concrete Columns with Carbon Fiber-Reinforced Polymer for Seismic Resistance, Journal of Structural Engineering, ACI, 100(S81) (2003).

[6]S. Bousias, Triantafillou T, Fardis M, S. L, O.R. B., Fiber-Reinforced Polymer Retrofitting of Rectangular Reinforced Concrete Columns with or without Corrosion, Journal of Structural, ACI 101 (4) (2004) 512-520.

[7]Y.S. Youcef, S. Amziane, M. Chemrouk, The Influence of CFRP on the Behavior of Reinforced Concrete Subjected to Buckling, in: Proc. of the: 4th International Conference on FRP Composites in Civil Engineering, Zurich: Switzerland, 2008.

[8]M. El Sayed, T. El Maaddawy, Analytical Model for Prediction of Load Capacity of RC Columns Confined with CFRP under Uniaxial and Biaxial Eccentric Loading, Journal of Materials and Structures, 44 (2011) 299-311.

[9]W Punurai, C. T. T Hsu, S Punurai, J Chen, Biaxially Loaded RC Slender Columns Strengthened by CFRP Composite Fabrics, Journal of Engineering Structures, 46 (2013) 311-321.

HOW TO CITE THIS ARTICLE

K. Nadimi Shahraki, M. Reisi, Strengthening Optimization of RC Columns with Rectangular Section by FRP Wrapping, Amirkabir J. Civil Eng., 51(6) (2020) 355-358.

DOI: 10.22060/ceej.2018.14493.5672