

Finite Element Analysis of Corner Strengthening of CFRP-Confined Concrete Column

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Abstract. Strengthening of the concrete structure is one of the most difficult and important tasks of civil engineering. This paper presented the application of nonlinear finite element models in the analysis of Corner Strengthening of CFRP- Confined Concrete Column by using ANSYS software. The finite element models are build using a smeared cracking approach for concrete material and three dimensional layered element for the CFRP composite. The numerical results are compared with the corresponding experimental results of columns. The results show that the stress- strain curve obtained from the analytical data using ANSYS are in good agreement with experimental data. In this paper, the parameters considered are: CFRP strip thickness and its elasticity modulus (locally added at corner column regions for strengthening) in addition to the corner column radius.

1. Introduction

The strengthening and seismic retrofit of reinforced concrete columns using Carbon Fiber Reinforced Polymer (CFRP) composite wrapped is based on a fixed reality, that lateral confinement significantly increase compressive strength of concrete and maximum strain. In a circular columns under to axial compression, the uniformly confined concrete by the FRP jacket. the compressive strength and the stress- strain behavior of such concrete has been broadly studied. However, much less is known about the behavior of confined concrete square columns by FRP, in which the confining stress varies through the cross-section of concrete and only part is effectively confined [1]. As a result, the confinement effectiveness is very reduced [2] and encircling the corners (usually right angle) generally recommended to increase effectiveness of confinement and to decrease the damaging results of a sharp edge of corner on the rupture strength of FRP.

In modern years, the use of externally FRP has become increasingly popular for civil applications. The behavior of FRP wrapped concrete cylinders with different of wrapping dimensions and bonding materials has been investigated by [3] using the finite element analysis (F.E.A.) and analytical approach. It was concluded that mechanical properties such as elasticity modulus and Poisson's ratio of FRP wrapping is governed load-carrying capacity of the wrapped concrete structure. The analytical compressive behavior of concrete members reinforced with externally FRP was investigated by [4],[5] and the difference in the cross-section shape was analyzed.

The effect of radius of corner on the behavior of confined square concrete columns by CFRP has been investigated by [6]. The angle radius is directly proportional to the increase in strength of the confined concrete. Edge smoothing of cross-section of reinforced concrete square columns draw a



signification part in delaying the rapture at the edge for the FRP composite. load carrying capacity in case corner radius equal to concrete cover better result than case of corner radius less than concrete cover for confined reinforced concrete columns [7]. The corner strengthening applications to rectangular and square concrete-filled FRP tubes having different corner radius has been investigated by [8]. The results indicate that compressive behavior can be enhanced through corner strengthening by additional CFRP strips. A study on the behavior of the FRP-confined circularized square columns compared to the fully FRP- square columns without circularized has been described by [9]. it was found by the study that the circularization section for square column can significantly improve the confinement effectiveness.

2. Finite Element Modeling

The calibration of finite element model included checking the model by comparing the nonlinear finite element results of a confined concrete column with the corresponding experimental results available in reference [8].

2.1. Concrete

Solid65 element was utilized to create the concrete in ANSYS software . each element has eight nodes which has three degrees of freedom and translation in all directions (x, y and z axis) .This element is cracking capable in three orthogonal directions under tension , crushing capable under compressive and plastic deformation. A representation of Solid65 is shown in Figure 1. The cracking is modeled by smeared crack approach

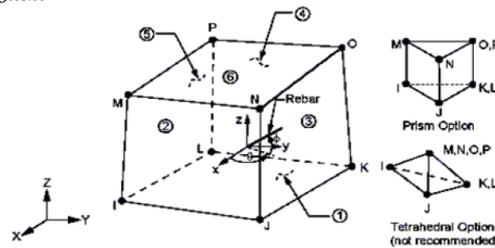


Figure 1. Solid65 element geometry [10]

The multi-linear isotropic curve, calculated by the below equations [11] and shown in figure 2, represented the adopted uniaxial stress-strain relationship for compressive concrete properties.

$$f_c = \varepsilon E_c \quad \text{for} \quad 0 \leq \varepsilon \leq \varepsilon_1 \quad (1)$$

$$f_c = \frac{\varepsilon E_c}{1 + \left(\frac{\varepsilon}{\varepsilon_0}\right)^2} \quad \text{for} \quad \varepsilon_1 \leq \varepsilon \leq \varepsilon_0 \quad (2)$$

$$f_c = f'_c \quad \text{for} \quad \varepsilon_0 \leq \varepsilon \leq \varepsilon_{cr} \quad (3)$$

$$\varepsilon_0 = \frac{2f'_c}{E_c} \quad (4)$$

The simplified uniaxial stress - strain curve for concrete material is founded from multi points linked by straight lines. the first point of the curve is zero value for the stress and strain of each. the second point in linear level subject to hook's law where strain (ε_1) calculated from curve at stress $0.3f'_c$. the points after the linear level until strain (ε_0) at stress f'_c , strain (ε_0) is obtained from equation (4), the stresses were calculated from equation (2).The behavior of concrete was perfectly plastic after strain (ε_0) up to crushing strain which is taken equal to 0.003.

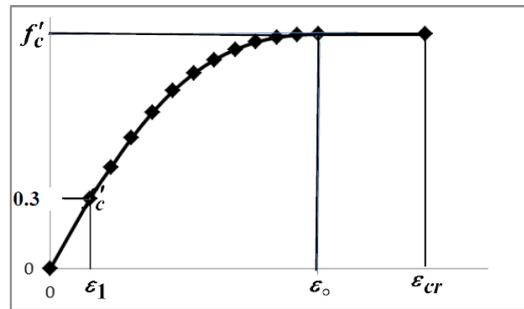


Figure 2. Multilinear uniaxial stress-strain curve for compressive concrete properties.[12]

2.2. Steel plate

To avoid stress concentration problems, added the plates of steel under the finite element models at the support and above it at loading locations in (similar to that in the original columns). The plates of steel were given to be linear elastic materials. The modulus of elastic (200 GPa) and Poisson’s ratio (0.3) were used for the plates of steel.

Solid45 elements were utilized to model the plates of steel . The geometry and locations of node for this element were similar to that of element Solid65 as shown in Fig.(1)[10]. The dimensions of steel plates that were used to represent the support and loading plates are equal to 150mmx150mm x 15mm.

2.3. CFRP Laminates

CFRP composite is material that consist of two constituents joint at a macroscopic stage and are dissoluble in each other. The Carbon Fiber tissue represented as first constituent , which is embedded in the continuous polymer (matrix) represented as second constituent. The CFRP composites are orthotropic materials (property is different in all directions). A Shell 99 layered elements were applied to model CFRP composites. The geometry and node positions for Shell 99 are shown in Figure 3.

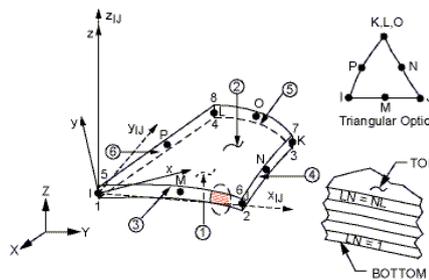


Figure 3. Shell 99 element geometry [10].

A review of properties of material for CFRP composites used in the present study for the finite elements modeling of corner strengthening column are given in Table 1 [8].

Table 1. Material properties for CFRP composite.

| Ultimate tensile stress | Ultimate tensile strain | Elasticity modulus | thickness |
|-------------------------|-------------------------|--------------------|-----------|
| 4370 MPa | 0.019 | 230 GPa | 0.111 m |

3. Geometry and Material Properties

Two columns with different geometry and loading conditions are analyzed using ANSYS finite elements model. Table 2 shows details of the confined concrete columns (Square CFFT) that were analyzed in the present study.

Table 2. Details of the analyzed columns

| Symbol | Description | Corner radius (mm) | CFRP Strips @corner | Thickness of CFRP strip (mm) |
|-----------|--|--------------------|---------------------|------------------------------|
| S-CR10-L0 | Square CFFT column with corner Radius 10 mm & corner unstrengthening by CFRP Strip [8] | 10 | 0 | - |
| S-CR10-L1 | Square CFFT column with corner Radius 10 mm & corner strengthening by One CFRP strip [8] | 10 | 1 | 0.111 |

Notes : CFFT means Confined concrete – Filled FRP Tubs

The geometry of the analyzed columns are shown in Figure (4), and the material properties adopted of the analyzed columns are given in Table (3).

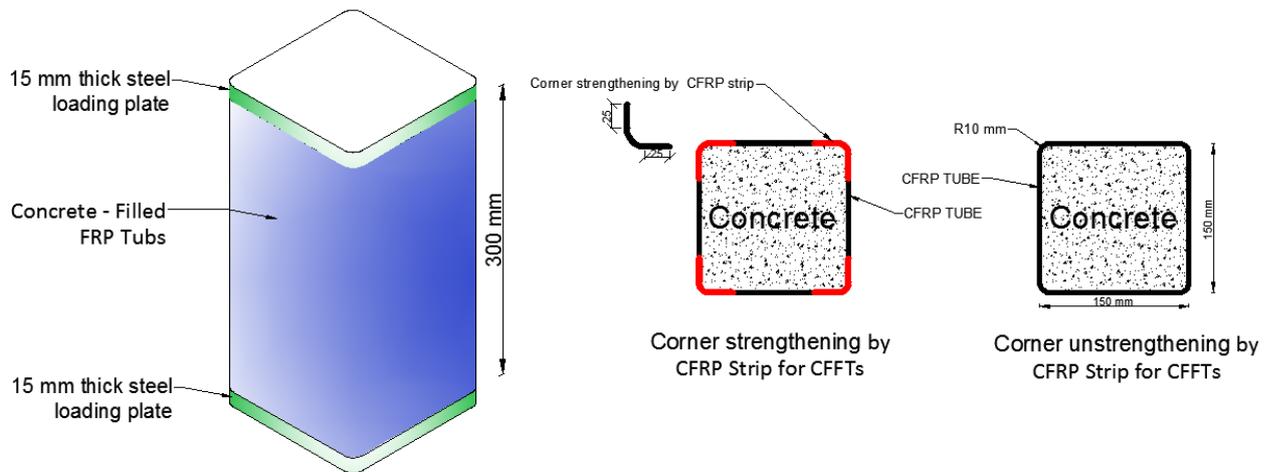


Figure 4. Geometry of the analyzed columns [8].

Table 3. Material properties of the analyzed columns[8].

| Materials | Properties | Value |
|-----------|----------------------|-----------|
| Concrete | Possions Ratio | 0.2 |
| | Compressive strength | 38.5 Mpa |
| | elasticity Modulus | 29140 Mpa |
| | Tensile strength | 3.85 Mpa |

4. Validation of the Finite Element Model

The Results of finite element analysis from the ANSYS program and the experimental results presented by [8] were compared by the axial stress – strain curve of each of the results in figures 5 and (6) , at the midpoint of the column height, for two cases of columns (S-CR10-L0) and (S-CR10-L1). When these shapes are observed, a good degree of compatibility was between both experimental and finite element results. The values of ultimate stress and strain calculated by analysis of the finite elements for Square CFFT (concrete –filled FRP tubes) columns with radius of corner of 10 mm is closer to the experimental results which shown in Table 4.

It can be clear that the proportion of the experimental to numerical axial stress and axial strain ranges between 1.018-1.012 and 1.089-0.947 , respectively. These results establish the effectiveness of finite element models for the analysis of square CFFT columns with corner radius of 10 mm.

Table 4. Experimental [8] and numerical values of axial stress and strain

| Column | Axial stress [MPa] | | | Axial strain [mm/m] | | |
|-----------|--------------------|--------|---------------|---------------------|--------|-------------|
| | EXP. | F.E.M. | F.E.M. / EXP. | EXP. | F.E.M. | F.E.M./EXP. |
| S-CR10-L0 | 40.1 | 40.6 | 1.012 | 0.0509 | 0.0482 | 0.947 |
| S-CR10-L1 | 42.2 | 43 | 1.018 | 0.0615 | 0.067 | 1.089 |

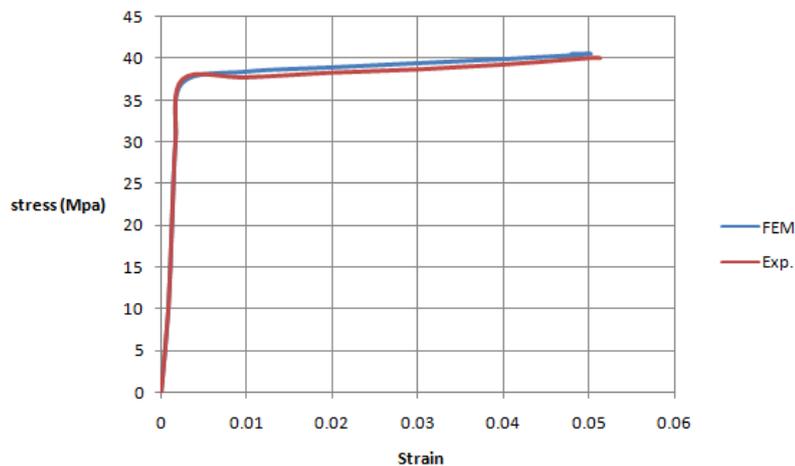


Figure 5. Experimental and numerical stress-strain curve of CFFT column with corner unstrengthening by CFRP Strip (S-CR10-CL0)

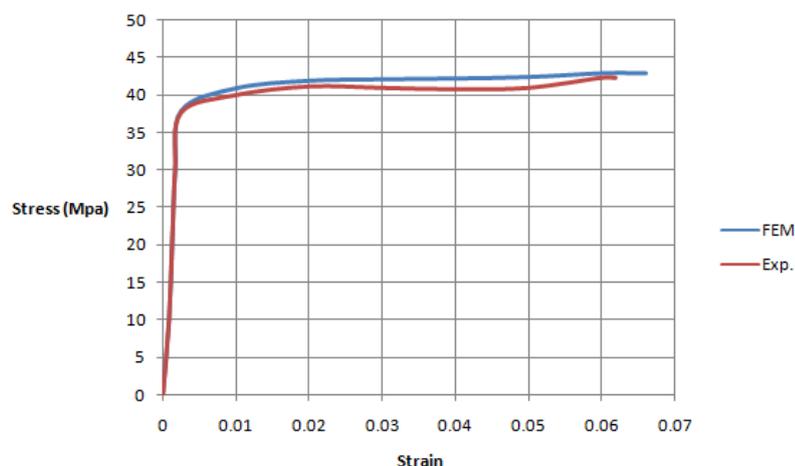


Figure 6. Experimental and numerical stress-strain curve of CFFT column with corner strengthening by One CFRP strip (S-CR10-CL1)

5. Results and discussion

5.1. Effect of Thickness of CFRP

To study the effect of CFRP strips thickness for strengthening of corner on the behavior of square CFFT columns. Three CFRP strip thicknesses 0.222, 0.333 and 0.444mm (This thickness can be achieved by using multilayers of CFRP strips of thickness 0.111mm) were used in addition to the original strip thickness 0.111mm.

Figure 7 reveals that the increase of strip thickness with values (0.222,0.333 and 0.444mm) leads to increases in the ultimate stress with percentages of (2.3% ,9.3% and 14%) and increases in the gained ductility with percentages of (5.9% , 22.4% , 50.74%) (So can be concluded that) , respectively as compared with original specimen. So, it can be concluded that using three times of the original CFRP strip thickness is significant in increasing ultimate stress and ductility of corner strengthening of confined square concrete column .

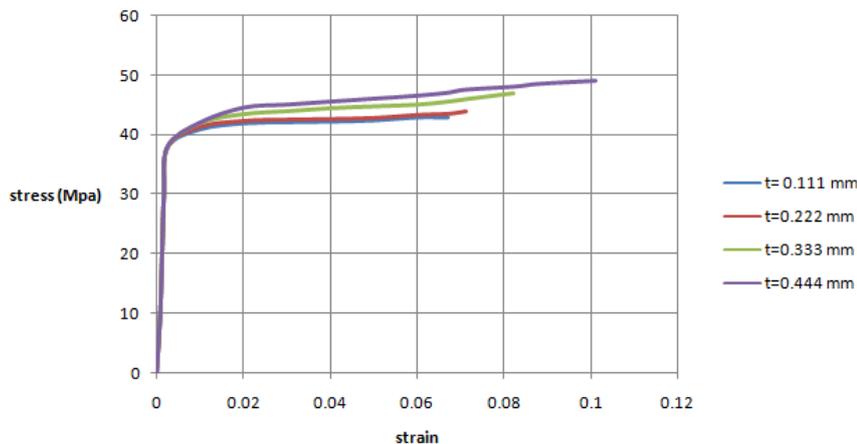


Figure 7. Stress-strain curves using F.E.M. for different CFRP strips thicknesses for Corner strengthening

5.2. Effect of Elasticity Modulus of CFRP strips

Three values of elasticity modulus of (340 GPa ,430 GPa and 605 GPa) for corner strips were selected arbitrary but in the range of modulus of elasticity mentioned in "ACI committee 440.22R-08" other than the original value (230 GPa).

It can be concluded that the ultimate stress and ductility are (11.6%, 28% and 51.2%) and (19.4%, 49.25% and 123.88%), as compared with controls , respectively. which shown in figure 8.

From the above percentages, the essential parameter in corner strengthening of square CFFT column significantly enhance ductility and increase the ultimate stress which is represented by increase elasticity modulus in high levels.

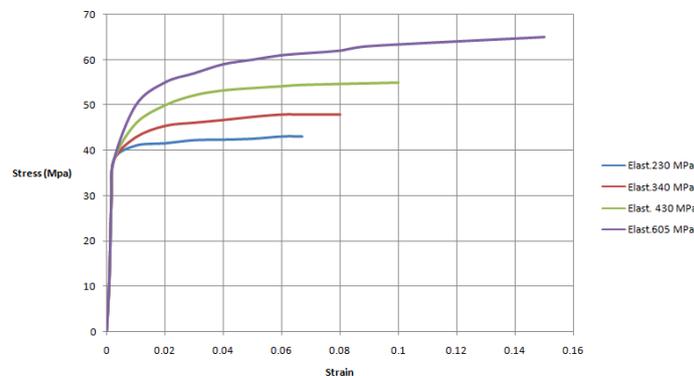


Figure 8. Stress-strain curves using F.E.M. for different values of elasticity modulus of CFRP strips for Corner strengthening

5.3. Effect of Corner Radius of Cross Section

Three corner radius were tried (15, 25 and 30mm). From Figure 9, it is noted that the reduce in corners sharpness of the area by increasing the radius of corner with the values of (15mm, 25mm and 30mm) results increases in ultimate stress of square CFFT columns strengthened with CFRP strips, as compared with original (corner radius 10 mm) by percentage about (32.6%, 51.2% and 65.8 %) , respectively, and decreases in ductility by percentage about (31.6% , 37.8% and 47.8 %) , respectively. This is referred to the reality that the strips of CFRP carries a high additional stresses of confining concrete as sharpness of the corner decreases because of the expansion in region of hoop tension which take place in corners of column and extends towards its sides .

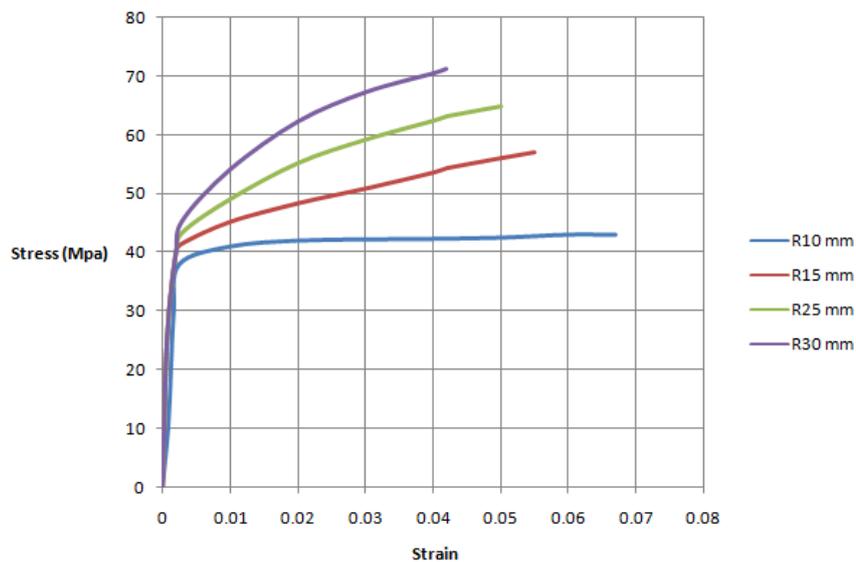


Figure 9. Stress-strain curves using F.E.M. for different values of corner radius of CFRP strips for Corner strengthening.

6. Conclusions

Based on analysis of nonlinear finite element, the results of Corner Strengthening of CFRP- Confined Concrete (CFFTs) Column by using ANSYS software, the following points can be drawn:

- 1-The general performance of stress-strain curves in finite element software at midpoint in height of the columns shows good degree of compatibility with stress-strain curves in the available experimental.
- 2- The gain in ultimate stress and ductility for corner strengthening of confined columns with CFRP increases with the thickness of CFRP Strip. When the thickness of CFRP strips is changed from (0.222 to 0.444 mm), the gained increase in ultimate stress ranges from (2% to 14%) and the gained ductility increases from (6% to 50.74%), as compared with the control column, respectively.
- 3-The elasticity modulus of CFRP for corner strengthening is more effectual than the CFRP thickness in increasing the ultimate stress and the ductility. Increasing the values of the elasticity modulus from 340 GPa to 605 GPa , results in an increase in gained ultimate stress from (11.6 % to 51.2 %) and gained ductility from (19.4 % to 123.9 %), as compared with the control column, respectively.
- 4- Decrease of sharpness of corner for square column area by the increase of radius of corner is a especially effectual parameter in enhancing the gained raise in ultimate stress and drop off ductility. When corner radius is increased from (15mm to 30mm), the gain in ultimate stress increases from (32.6 %to 65.8 %), and the gained ductility decreases from (31.6 %to 47.8 %).

7. References

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