ASSESSING STRUCTURAL BEHAVIOUR OF FRP-CONFINED CFST COLUMNS THROUGH FINITE ELEMENT METHODS

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Abstract- While several studies have examined the use of sparse and limited data to predict the load-carrying capacity (LC) of fiber-reinforced polymer (FRP)-confined concrete-filled steel tube (CFST) compression members (FCC). But none have examined the predictive accuracy of different modeling approaches with a large and comprehensive dataset. Creating a finite element model (FEM) to forecast the axial compressive performance of FCC compression components is the main goal of this research. The steel tube and FRP wraps are represented by bilinear and linear elastic models, respectively. The concrete is represented by a concrete damage plasticity model. The proposed FEA model showed minor variations of only 6.70% and 3.10% for the maximum LC and related axial shortening of FCC columns, respectively.

Keywords- Database, finite element analysis; CFST; damaged plastic model; axial strength

1 Introduction

When restricted with steel tubes (ST) and fiber reinforced polymer (FRP), concrete compression members demonstrate remarkable mechanical performance and adaptability. In civil engineering projects like long-span bridges and multistory buildings, these members are heavily utilized [1]. A precise simulation of axial compression strength is achieved using a nonlinear finite element analysis (FEA) of concrete filled stainless steel tube (CFST) compression members, which use an updated concrete damaged plastic model [2]. There is a good consistency between numerical estimations and experimental results in another FEA investigation of CFST compression members that uses an upgraded damaged plastic model to evaluate axial load-deflection and load-bearing capacity with ABAQUS [3]. Raza et al. [4] investigated reinforced concrete compression members wrapped with FRP sheets using FEA, utilizing both the linear elastic model and an updated version of the damaged plastic model. To accurately replicate the structural behavior of compression elements, another study looked at the effects of a number of characteristics, such as lateral FRP confinements and the interaction mechanism between lateral steel-tubes, FRP wraps, and concrete [5]. Similarly, a general fiber element model was developed to incorporate ultimate strength and axial compression behavior to predict the load-bearing strength of CFST circular components [6].

Previous empirical models did not consider factors unique to FRP confinement, such as interaction between FRP wraps, steel tubes, and concrete. Instead estimated the load carrying capacity (LC) of FRP-confined CFST compression members (FCC) using sparse experimental data. Therefore, more study will be needed to create a more thorough sample that can estimate the load carrying capacity of FCC compression members. The authors of this study used an experimental database and ABAQUS-based FEA modeling to assess the effectiveness of FCC compression members.

2 Finite Element Analysis

2.1 General Methodology

Currently, ABAQUS 6.14 tool is being used to do the finite element analysis of FCC compression members [7]. To replicate the behavior of axial shortening, eight FCC compression members were selected [8]. The primary characteristics of the modeled FCC members are shown in Table 1. To represent the restricted concrete, 4 node curved shell components and 8 node brick elements in 3D were used (see Figure 1), together with steel tubes (ST) and carbon fiber reinforced polymer (CFRP) wraps. These element kinds were chosen because they could faithfully depict the behavior of compression elements [4]. The concrete was poured into the steel tubes (ST) and stirred, in accordance with the guidelines of a prior study. A homogenous and flowable concrete mix was made in order to guarantee consistency of the mix inside the ST. The top of the ST was then welded with a steel plate to apply load. 150 mm x 150 mm x 150 mm cube samples were created to evaluate the concrete's compressive strength.

Table 1. Characteristics of modelled FCC samples

Sample name	H (mm)	D (mm)	D/t_s	t_s (mm)	t_{cf} (mm)	n_o	f'_{co} (MPa)	K_ε
D200-C40-L2	600	200	100	2	0.334	2	40	0.575
D200-C40-L4-S1	600	200	100	2	0.668	4	40	0.677
D200-C60-L2	600	200	100	2	0.334	2	60	-
D200-C60-L4-S1	600	200	100	2	0.668	4	60	0.567
D260-C40-L2	780	260	130	2	0.334	2	40	0.701
D260-C40-L4-S1	780	260	130	2	0.668	4	40	0.420
D260-C60-L2	780	260	130	2	0.334	2	60	-
D260-C60-L4-S1	780	260	130	2	0.668	4	60	0.449

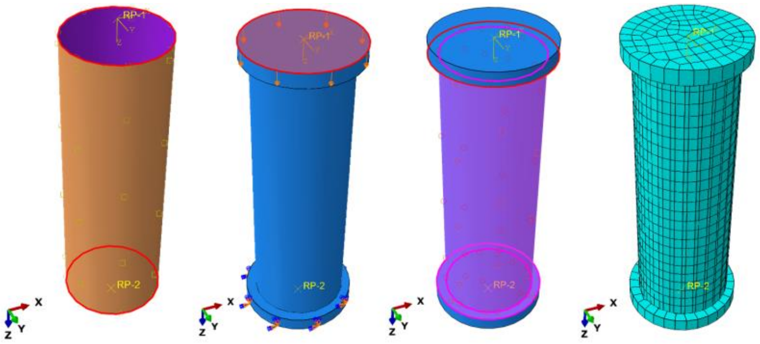

Figure 1. FEA simulations (a) steel tube, (b) application of loads, (c) interactions, and (d) meshed elements

The damaged plasticity model from the ABAQUS library was used to simulate restricted concrete, and it demonstrated a high degree of accuracy in representing the inelastic response of concrete under compression [6]. To precisely replicate the high-strength properties and damage behavior of CFRP wraps, the Hashin damage model [4] was used. Equations (6) through (9) of this model demonstrate its well-known capacity to characterize the beginning of damage in the medium and fibers under tensile and compressive loads [4].

Mode 1: fiber tension

$$f_1 = \left(\frac{\hat{\sigma}_{11}}{X^T}\right)^2 + \alpha\left(\frac{\hat{\sigma}_{12}}{S^L}\right)^2, \text{where } 0 \leq \alpha \leq 1 \tag{6}$$

Mode 2: fiber compression

$$f_2 = \left(\frac{\hat{\sigma}_{11}}{X^c}\right)^2 \tag{7}$$

Mode 3: matrix tension

$$f_3 = \left(\frac{\hat{\sigma}_{22}}{Y^T}\right)^2 + \left(\frac{\hat{\sigma}_{12}}{S^L}\right)^2 \tag{8}$$

Mode 4: matrix compression

$$f_4 = \left(\frac{\hat{\sigma}_{22}}{2S^T}\right)^2 + \left[\left(\frac{Y^c}{2S^T}\right)^2 - 1\right]\frac{\hat{\sigma}_{22}}{Y^c} + \left(\frac{\hat{\sigma}_{12}}{S^L}\right)^2 \tag{9}$$

Where, X^C denotes the compression strength of fibers, X^T shows the fibers' tensile strength measured in the normal direction whereas Y^C designates the compression strength. Similarly, Y^T depicts the tension strength reported in the transverse direction of wraps.

2.2 *Discussion of FEM Results*

The behavior and comparison of the whole load-deflection plot for each of the FCC samples that were included in the FEA model are shown in Figure 2. In the elastic and plastic zones of the load deflection plots, the sample performed admirably. The standard FEA model showed minor variations of only 6.70% and 3.10% for the maximum LC and related axial shortening, respectively. In contrast to all other models, sample D260-C40-L4-S1 showed the biggest divergence, with a value of 8.90% for the highest LC. Although the FEA model demonstrated a stronger correlation with experimental results in the plastic stage, it underestimated loadings in the elastic zone.

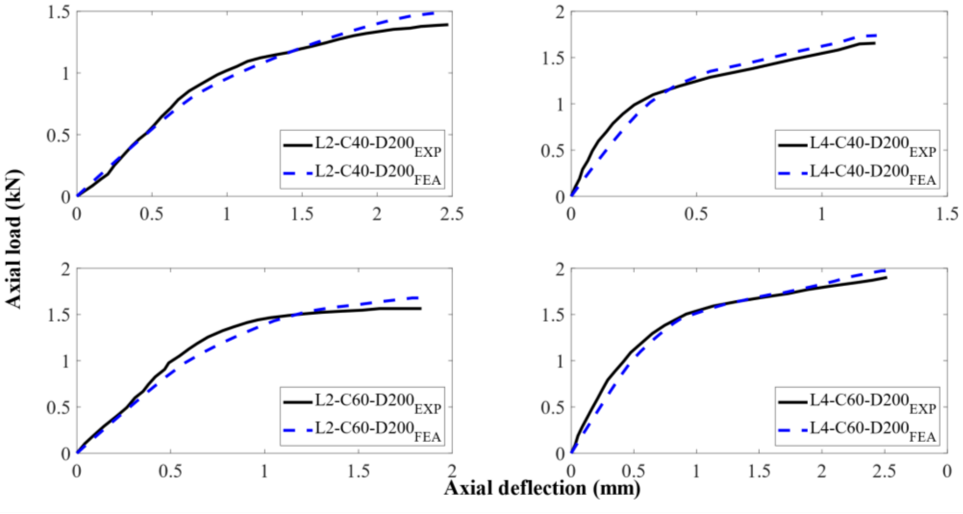

Figure 2. Running of FEA sample for the load deflection performance of FCC compression members

The study investigated the impact of increasing CFRP layers from two to four on Fiber-reinforced concrete (FCC) compression elements. Results showed a 19% and 21.50% increase in LC for D200-40 and D200-60 elements, respectively, with corresponding enhancements in axial shortening (see figure 3 and Figure 4). Similar improvements were observed for D260-40 and D260-60 elements. FEA calculations for D260-40 showed a 33.20% difference in ductility behavior and LC compared to experimental results, possibly due to disregarding residual stresses, variations in material properties, and assumptions in modeling.

2.2.1 *Failure Patterns*

Experimental testing of FCC members showed a linear elastic relationship between axial shortening and LC until ST yielding. Lateral confinement from CFRP wraps and ST led to a second linear segment in load-deflection, but LC dropped after CFRP fracture and ST buckling, indicating shear, and crushing failure. FE simulations matched lab results being visualized through positive principal plastic stains [9-10], showing shear failure in FCC members with fewer CFRP layers and higher core strength, and crushing failure in those with lower core strength (Figure 4).

(a)

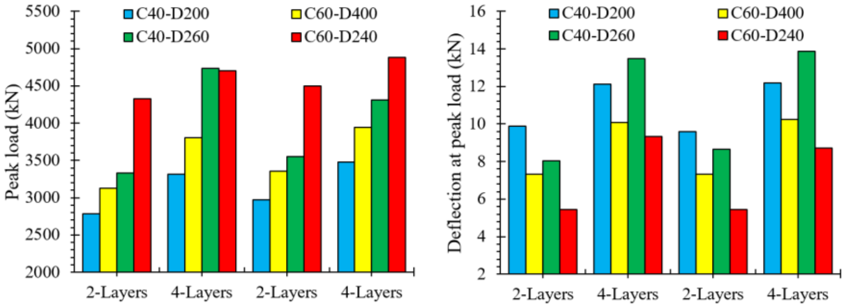

Figure 3. Influence of number of CFRP sheets (a) LC and (b) axial shortening of FCC compression members

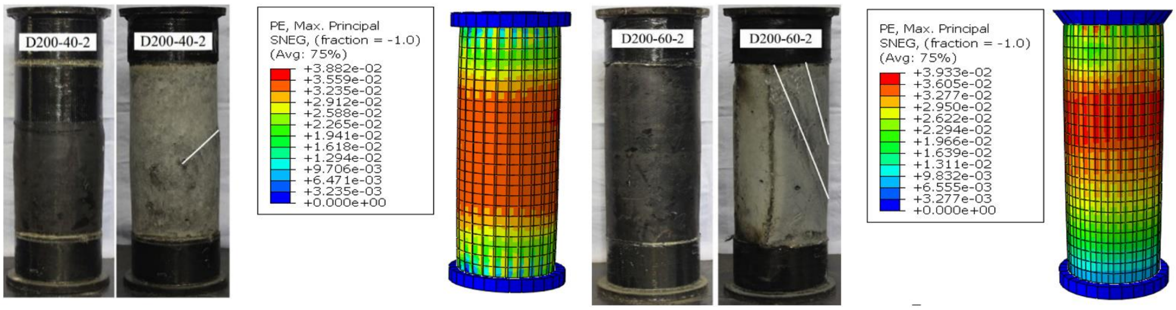

Figure 4. Failure modes of samples

3 Conclusion

This study's nonlinear finite element model, which accounts for the confinement offered by CFRP and ST confinement, successfully replicated the behavior of these parts. With differences of 5.72% and 2.83%, respectively, the FEA-based model's predictions for the members' axial shortening and LC exhibited only minor variations. The model used the Hashin damage model for CFRP covers, an updated concrete damage plasticity sample for the core concrete, and bilinear modeling for ST.

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