Comparison of ultimate strength results from ACI and Eurocode 4 for steel tubular columns filled with SCC

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Abstract. The Concrete Filled Steel Tubular (CFST) columns have several benefits in comparison to the ordinary steel or reinforced concrete ones. Therefore, they have become more commonly acknowledged in the structural applications. In this study, two design codes such as American Concrete Institute (ACI) and Eurocode 4 (EC4) were used for predicting the ultimate axial strength of CFST columns filled with self-compacting concrete (SCC). To evaluate the results, circular steel tube with different diameter to thickness (D/t) ratio of 30, 60, and 90 and steel yielding strength of 185, 275, and 450 MPa were considered as prediction parameters. The wall thickness and length to diameter (L/D) ratio of the steel tubes were kept constant. As an infill material for the steel tubes, 16 different SCC mixtures reported in the literature were studied and their compressive strength results were used to get the code predicted ultimate axial strength of the composite columns. The analysis of the results based on ACI and EC4 were performed and discussed comparatively.

1 Introduction

Composite columns that have been widely used in the engineering applications have superior strength and ductility properties. When the traditional reinforced concrete columns are compared with the Concrete Filled Steel Tubular (CFST) columns, significant differences with respect to ductility and energy absorption capacity can be observed. Due to their outstanding static and dynamic characteristics, CFST columns have been commonly utilized in the various types of structures such as bridges, high-rise buildings, subway platforms, etc. [1-7]. The load carrying capacity of the column is significantly influenced by the properties of steel and concrete. Due to the progress in the strength of steel and concrete, cross section of the structural elements gets smaller. Steel in CFST columns is used to confine the concrete that is the structural advantage of CFST and provides contribution in load carrying capacity. In addition, the construction time is also reduced by eliminating the permanent formwork. Also, the utilization of CFST in structures procures an inhibited or delayed local buckling of steel tube due to the concrete core. Briefly, increase in the load carrying capacity, stiffness, and ductility and decrease in the cost and time of construction by use of CFST columns make utilization of such columns attractive [7].

The CFST columns have been experimentally investigated for decades [6-11]. Researches revealed that the properties and geometry of the materials are leading parameters which remarkably affect the behavior and

capacity of CFST columns. For the last few years, there have been a plenty number of theoretical and experimental studies on circular CFST columns with several diameter to thickness (D/t) ratios with combinations of various material properties [2,12-17]. Since the experimental investigation of axial load carrying capacity of CFST columns extensively attracts the interests of researchers, the theoretical analysis, therefore, plays a significant role in engineering research and practice.

In this study, the formulas proposed by ACI 318 and Eurocode 4 [18,19] were used for the calculation of the ultimate strength of steel tubular columns infilled with self-compacting concrete (SCC). For this, several parameters were considered such as different D/t ratios and steel yield strength of steel tube and compressive strength of SCC core. A comparison of the analysis results based on both design codes was performed for the composite columns under the action of compressive loading.

2 Details of the study

To evaluate the behavior of SCC filled steel tubular columns subjected to axial compression, as previously mentioned, two international design codes were employed. To this aim, three ratios of D/t (30, 60, 90) and three yield strength of steel, f_y (185, 275, 450 MPa) were specified for circular CFST columns. However, a constant length to diameter (L/D) ratio and steel tube thickness of 2.5 and 4 mm was considered. A special procedure was adopted to take the benefit of

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compressive strength results of SCC as an infill material on the behavior of CFST columns. For this, the concrete strength was used from the experimental studies of Güneyisi et al. [20] and Al-Goody [21]. According to these works, a total of 16 SCC mixtures were designed with respect to various nanosilica, NS (0-6%) and fly ash, FA (0-75%) contents. Their cubic compressive strength results at 28 days varied from 30 to 78 MPa. More detailed explanations on the properties of the mixtures can be found in the aforementioned study. It should be noted that the cubic compressive strength results were converted to cylindrical compressive strength by using Eurocode 2 [22] and then used in the calculation of ultimate strength of the steel tubular columns regarding to ACI 318 and EC 4 [18,19].

There are a number of expressions given by the standardization institutes of several conditions [18,19]. The formulae used in this paper are proposed by ACI 318 and Eurocode 4. The American Concrete Institute [18] uses the following expression for calculating the ultimate axial capacity of the circular CFST columns.

$$N_u = 0.85f'_c A_c + f_y A_s \quad (1)$$

This relation does not contain effectiveness of the concrete confinement and the interaction between the concrete core and steel tube. However, in the relation suggested by Eurocode 4 [19], the contribution of the steel tube and the concrete core as well as confinement effect is taken into account. The coefficients of confinement for the concrete (η_c) and steel tube (η_a) are employed. Thus, the concrete strength is increased by η_c due to the occurrence of a triaxial state of stress condition while steel tube strength is reduced by η_a since the hoop stresses cause a reduction in the effective yield stress of the steel. The following expression is proposed by Eurocode 4 [19]:

$$N_u = \left(1 + \eta_c \frac{t}{D} \frac{f_y}{f'_c}\right) f'_c A_c + \eta_a f_y A_s \quad (2)$$

$$\eta_c = 4.9 - 18.5\bar{\lambda} + 17\bar{\lambda}^2 \quad (\eta_c \geq 0) \quad (3)$$

$$\eta_a = 0.25(3 + 2\bar{\lambda}) \quad (\eta_a \leq 1.0) \quad (4)$$

$$\bar{\lambda} = \sqrt{\frac{N_{pIR}}{N_{cr}}} \quad (5)$$

$$N_{pIR} = f_y A_s + f'_c A_c \quad (6)$$

$$N_{cr} = \frac{\pi^2 (EI)_{eff2}}{l^2} \quad (7)$$

$$(EI)_{eff2} = E_s I_s + K_e E_{c2} I_c \quad (8)$$

$$P_{o,EC4} = \left(1 + 4.9 \frac{t}{D} \frac{f_y}{f'_c}\right) f'_c A_c + 0.75 f_y A_s \quad (if \bar{\lambda} = 0) \quad (9)$$

3 Results and discussion

The compressive strength of SCC mixtures at 28 days were used in the calculation of the ultimate strength of the steel tubular columns by using ACI and Eurocode 4 formulae. The relation between ultimate strength (calculated by using ACI and Eurocode 4 formulae) and NS/FA contents are presented in Figure 1 with respect to D/t ratio of 30 and steel yielding strength of 185 MPa. In the other figures, the relations are given with respect to D/t ratio of 60 and 90 and steel yielding strength of 275 and 450 MPa (Figures 2-9). The results indicated that the ultimate strength of steel tubular columns filled with SCC is strongly affected by concrete compressive strength. Utilization of NS till replacement level of 4% increased the SCC compressive strength and an increase in the compressive strength directly increased the ultimate strength of the steel tubular columns. However, at the replacement level of 6%, a decrease in the compressive strength of SCC was observed at all FA contents. This is also caused decreasing in the ultimate strengths of CFST calculated by both formulae. On the contrary to NS, the utilization of FA decreased the compressive strength of SCC. This situation resulted in lower ultimate strength of steel tubular columns determined by both formulae. Moreover, the ultimate strengths determined by ACI formula were lower than that calculated by using Eurocode 4. Calculating the ultimate strength of the steel tubular columns filled with compressive strength at different D/t ratio showed that increasing the concrete surface area increases the ultimate strength. Also, utilization steel tubular with higher yielding strength remarkably increases the ultimate strength of the columns.

Fig. 1. Axial capacity of CFST columns with D/t value of 30 and f_y of 185 MPa having different SCC mixtures according to: a) ACI and b) Eurocode 4

Fig. 3. Axial capacity of CFST columns with D/t value of 90 and f_y of 185 MPa having different SCC mixtures according to: a) ACI and b) Eurocode 4

Fig. 2. Axial capacity of CFST columns with D/t value of 60 and f_y of 185 MPa having different SCC mixtures according to: a) ACI and b) Eurocode 4

Fig. 4. Axial capacity of CFST columns with D/t value of 30 and f_y of 275 MPa having different SCC mixtures according to: a) ACI and b) Eurocode 4

Fig. 6. Axial capacity of CFST columns with D/t value of 90 and f_y of 275 MPa having different SCC mixtures according to: a) ACI and b) Eurocode 4

Fig. 5. Axial capacity of CFST columns with D/t value of 60 and f_y of 275 MPa having different SCC mixtures according to: a) ACI and b) Eurocode 4

Fig. 7. Axial capacity of CFST columns with D/t value of 30 and f_y of 450 MPa having different SCC mixtures according to: a) ACI and b) Eurocode 4

Fig. 9. Axial capacity of CFST columns with D/t value of 90 and f_y of 450 MPa having different SCC mixtures according to: a) ACI and b) Eurocode 4

Fig. 8. Axial capacity of CFST columns with D/t value of 60 and f_y of 450 MPa having different SCC mixtures according to: a) ACI and b) Eurocode 4

In addition, in Figure 10, the correlation between the design codes for the composite sections having different SCC mixtures was given. Results indicated that there is a strong relation between the ultimate strength calculated by ACI and Eurocode 4 formulae.

Fig. 10. Correlation between the design codes

4 Conclusions

Based on the findings of the study, the following conclusions can be drawn.

- The compressive strength of the concrete and the yield strength of steel have an important influence on the ultimate strength of the circular steel tubular columns filled with concrete.
- FA and NS contents significantly affect the strength of SCC and CFST columns.
- Variation in diameter to thickness ratio is observed to be remarkable effects on the ultimate strength of the circular steel tubular columns filled with SCC.
- Ultimate strength calculated by using ACI formula resulted in lower values than that calculated by Eurocode 4.
- There is a strong relation between ultimate strength values obtained by using ACI and Eurocode 4 formulae.

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