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Finite Element Modeling and Behavior Analysis of Axially Comprised Circular Dual Tube Columns Filled with Concrete

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***Abstract*- CFDST is an abbreviation that stands for concrete-filled columns that have a dual steel tube. In the past few years, there has been debate on the possibility of using these types of columns. As a consequence of this, the objective of this work is to develop and validate material modeling approaches that are considered to be suitable for use with concrete-filled columns (CFT) that have been exposed to axial compression loads. Using the ABAQUS program as the nonlinear finite element, the suggested models are evaluated by doing a comparison study with the experimental data. This analysis is carried out in order to validate the models. The models are supported by this investigation. In addition, parametric investigations are carried out in order to evaluate the influence that the different strengths of the concrete have on the axial behavior of circular CFDST stub columns. This is done so that a conclusion may be drawn on the significance of the influence.**

***Keywords*-Concrete-filled columns, Dual tube columns, Circular stub columns, Finite element modeling.**

I. Introduction

The utilization of tubular columns infilled with concrete (CFST) has gained increasing popularity in the process of constructing high towers due to the advantageous composite behavior exhibited by the combination of concrete with steel. Utilization of a composite system consisting of a core concrete combined with a steel tube leads to the core concrete being exposed to tri-axial pressure, thereby establishing a highly efficient compression element that facilitates composite action. The inclusion of a core concrete element within the steel tube serves to mitigate the occurrence of local buckling by offering internal support [1]. Consequently, this support leads to an increased capacity for compression resistance [2, 3]. Furthermore, it is important to take into account that circular tubes made of steel have the ability to provide significant confinement, enhancing the capacity of the concrete in the core [4, 5]. The tube serves as an external formwork in the concreting stage of the column, allowing for the complete utilization of the bending moment capabilities of the steel material [6]. Furthermore, the CFST column offers the benefit of being able to decrease the cross-sectional dimension of the column while still allowing the required load, hence leading to an expansion of the available net floor area [7]. Nevertheless, the installation of CFST columns is followed by several challenges. These include the formidable task of processing and manufacturing due to a steel tube's large thickness and inadequate fire resistance that necessitates costly fire-retardant coating spraying. Consequently, an increasing number of studies have proposed several strategies [8, 9] aimed at enhancing the efficiency of CFST columns. Notably, one approach that stands out is the utilization of dual steel tubular columns infilled with concrete, which effectively address the aforementioned limitations. In the previous years, CFDST columns have been suggested for usage, which is composed of both the inner and outer steel tubes with concrete filling [10]. Numerous researchers have examined into how CFDST stub columns behave when they are compressed axially. Fang et al. [11] conducted experiments on a total of 26 circular CFDST stub columns with a circular section that were compressed axially. The study focused on analyzing the behavior, type of failure, ductility, and ultimate strength of the members. In their study, Wan et al. [12] conducted an experimental examination on six stub columns (CFDST) with a circular section that were compressed axially. The researchers evaluated the impact of different ratios of steel and the inner tube yielding stress. The study revealed that columns made of Daul steel tubes filled with concrete (CFDST) exhibit greater capacity in comparison to columns made of a single tube filled with concrete (CFST). In their study, Peng et al. [13] conducted static load experiments on a total of 18 circular dual skin stub columns filled with concrete CFDST. The columns were filled with high-strength concrete and compressed axially. The researchers observed and documented the failure mechanisms and features exhibited by the columns under this loading condition. The authors, Chang et al. [14], conducted axial compression experiments on a set of four carbon and stainless-steel stub columns, which were filled with concrete. A proposed modification to the concrete's stress-strain model was put forth. The performance of short columns was examined using a model based on finite elements to study the impact of carbon steel tubular thickness, diameter, and yield strength. In their study, Hassanein et al. [15] introduced a novel model technique for the concrete in the core of circular stub columns consists of steel-carbon and lean duplex stainless steel tube. Chang's test was used to confirm that the model was accurate [14]. Subsequently, an investigation was conducted to examine the impact of concrete characteristic strength, carbon steel tube yielding stress, and section geometry on the columns' behavior. Furthermore, a novel design model that is appropriate for CFSCT was put out. The performance of steel short columns filled with high and ultra-high-stress components was investigated by a comparative investigation of short column specimens by Xiong et al. [16].

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Comparing the results to CFST columns without additional characteristics, the findings show that the addition of CFDST columns can produce additional confinement affects the concrete core, improving its ductility and strength. A fiber-based theoretical simulation for predicting the axial compression failure of steel short columns with a double skin circular tubes filled with concrete (CFDST) has recently been proposed by Ahmed et al. (17). The model has a high level of agreement with experimental validation. Ahmed et al. (17) introduced a simpler equation for determining the axial strength of studied columns. Numerous researchers have conducted several investigations on the behavior of CFDST columns compressed axially thus far. The objective of this study is to introduce appropriate technique for modeling the steel tubes, concrete between the outer and inner tube and concrete inside the inner tube within the finite element F.E simulation presented herein. The experimental findings of Fang et al. [11] are utilized to validate the preciseness of the F.E technique. The examination of the change in confining pressure levels from the steel tube on the concrete is consequently studied in a comprehensive manner using the verified numerical technique. Furthermore, variable analyses are also conducted to further examine the impacts of concrete strength on the axial compressive action of circular CFDST stub columns.

II. Numerical Modeling

1. *General concept of model*

The F.E modeling of composite short columns with a circular section was created employing the F.E program ABAQUS. Circular CFDST columns impose significant steel tube confining stress on the core concrete [14]. Hence, for the objective of accurately estimating the CFSDT short columns' behavior, the F.E model comprises an outer and inner steel tube; the area between tubes is filled with concrete, named shell concrete, and the inner tube is filled with concrete, called core concrete. Each part has been assigned distinct constitutive models. (S4R) and (C3D8R) used for the steel tube modeling and concrete core, respectively. In order to provide a furthermore reflection of the actual behavior of CFST columns, a comprehensive model was built for analysis of the column.

2. *Interaction and Imperfection*

In the ABAQUS software, the relationship between the tube and core concrete was addressed through the utilization of a surface-to-surface bond. In the normal direction, hard contact was utilized in the definition of contact performance [18]. A friction coefficient of 0.25 was employed in the penalty constraint. Other variables that affect contact behavior were adjusted to their default values [19]. Considering columns having L/D ratios between 2 and 5, it was typically observed that the influence was considered needless with regard to the initial defects [20]. However, the (F.E) analysis used in this work kept taking into account any initial defects. The first order buckling effect, with a value of L/1000, was employed to simulate the initial defect.

3. *Steel Modeling*

In the context of steel modeling, an elastic, perfectly plastic model was employed. The experimental value of the Young's modulus was utilized in relation to the elastic properties of steel, while the Poisson's ratio was assigned a standard value of vs = 0.3 and the steel modulus of elasticity was used 200 GPa. The experimentally measured stresses were taken into consideration as per the reference [11].

4. *Concrete Modeling*

Concrete was split into sandwich concrete in addition to core concrete in the F.E simulation of circular CFDST stub columns. It is noted that the concrete's Poisson's ratio ($\mu \approx 0.17$ s) is a lesser than the steel tube's ($\mu = 0.25:0.30$ s) during the initial load stage. Consequently, the concrete is not exposed to confinement by the inner and outer tubes [10]. As the load increases, it is shown that the concrete undergoes passive confinement when its lateral expansion surpasses that of the steel tube because of the radial pressure the steel tube applies. Consequently, the core concrete comes into a state of tri-axial compression stress. As a result, concrete gains in strength plus ductility. The confinement offered by the multiple steel tubes increases the capacity of core concrete even more. Hence, it is recommended that distinct constitutive models be employed in the F.E model for sandwich concrete as well as core concrete [15]. In this study, the modeling of concrete parts sandwich and core has been applied to stub columns with circular carbon steel tubes filled with concrete by Chang et al. [14]. Figure (1) presents the relationship between stress and strain adopted by Chang. The Drucker-Prager property is employed for the simulation of confined concrete in the plastic stage. The friction angle, dilation angle and flow stress ratio were reported to be 20°, 20° and 0.8 [21, 23- 24], respectively.

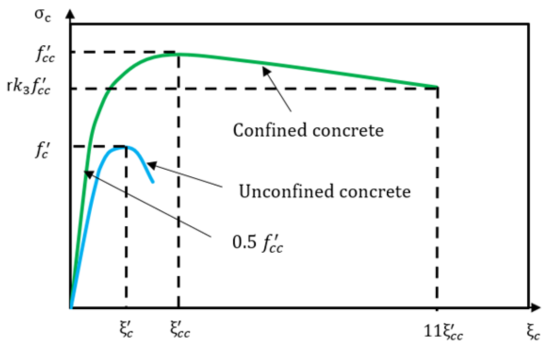

Figure 1. Curves of concrete modeling [14]

III. Analysis Findings and Discussions

For the purpose of preciseness of the constitutive model, this paragraph will conduct a comparative analysis of the maximum capacity and axial load - displacement relationship between the experimental tests and the F.E models. The nonlinear model can be assessed and validated in comparison

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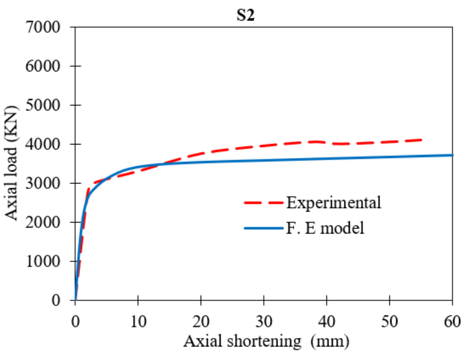
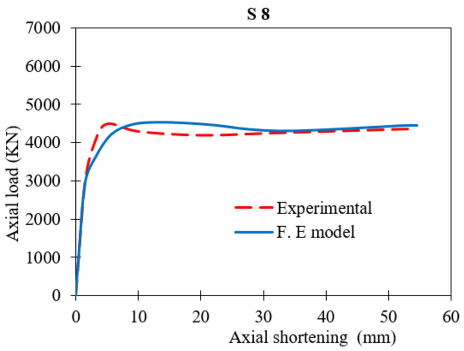
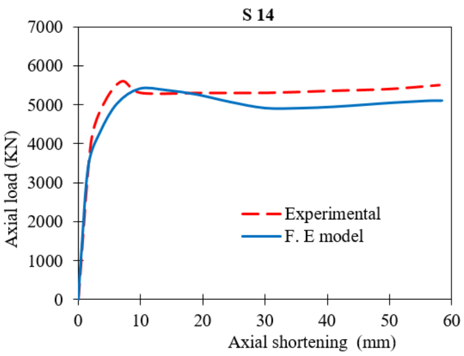
to the experimental findings. This section compares constitutive models using experimental results from CFDST short columns, including four specimens from Fang and Lin [11]. Table 1 details the size and material parameters of the studied specimens, the characteristic strength of unconfined concrete (f_{cu}) in the standard 150 mm cube and the strength (fc') of the cylinder (150 mm × 300 mm) in this work. It also compares the ultimate capacity ($P_{F.E}$) from F.E analysis to test results (P_{Exp}). Add a coefficient of 0.8 to the strength of the standard cube (f_{cu}) to obtain the strength of a concrete cylinder (fc'). Concrete (f_{cu}) employed during the simulation has a strength range between 40 MPa and 84.4 MPa, showing wide variation and more confidence. Figure (2). Illustrates the relationship between the load and axial displacement of some specimens utilizing the model technique proposed by Chang et al. [14].



(a)



(b)



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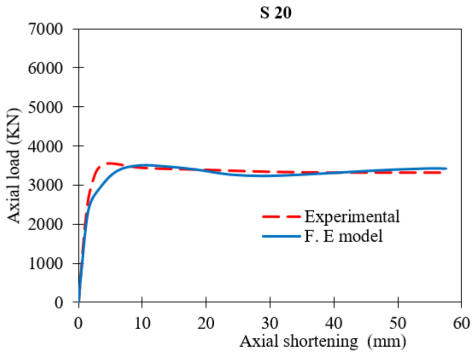

(d)

Figure 2. Load - displacement curves between experimental and F.E model

- The test findings (P_{Exp}) show satisfying agreement with the ultimate capacities ($P_{F.E}$) of numerical analysis.
- Regarding the stiffness of columns for most of the specimens, the (F.E) model exhibits an acceptable level of agreement with the experimental findings, but with a little variance during the plastic phase. Overall, the F.E model demonstrates a good level of preciseness in simulating the test outcomes. The (F.E) load-shortening relationship and the experiments that were conducted for certain examinations, including S2 and S14, have a few variations. The potential cause of the observed phenomenon can be attributed to the distortion of both end plates used in the specimen ends and the plate used for loading, as well as the inherent variability around the mechanical properties of the concrete material utilized in the conducted experiments.
- With respect to the ultimate failure mode exhibited by the specimens, Fang et al. [11] observed waist drum failure for the specimens S2, S8, S14 and S20. The F.E model has a good accuracy of simulating the failure mode shape of the samples.
- The Chang model [14] has the capability to simulate test findings with a higher degree of accuracy. Hence, for the next phase of analysis, the utilization of the technique for concrete modeling proposed by Chang et al. [14] is employed for the purpose of simulating the test and conducting an extensive parameter analysis.

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Table 1. CFDST samples' geometrical data and a comparison of modeling and experimental findings.

	D (mm)	t_o (mm)	D/t_o	f_{yo} (MPa)	d (mm)	t_i (mm)	d/t_i	f_{yi} (MPa)	L (mm)	f_{cu} (MPa)		P_{Exp} (KN)	$P_{F.E}$ (KN)	$P_{F.E} / P_{Exp}$
S2	219	6	36.5	312.5	102	6	17	321.7	880	40		4100	3724	0.91
S8	219	6	36.5	312.5	102	8	12.8	312.5	880	71.5		4498	4522	1.01
S14	219	8	27.4	325	102	6	17	321.7	880	84.4		5600	5402	0.96
S20	168	6	28	365	89	4.5	19.8	392.5	680	84.4		3545	3496	0.99

IV. Parametric Study

The verified F.E technique was utilized to investigate the impact of the characteristic concrete strength on the performance of circular (CFDST) short columns. To be able to mitigate the impact of overall buckling and end constraints on the ultimate capacity and performance of columns, a ratio of L/D equal to 3.89 is recommended [25].

A total of four CFDST stub columns were created in order to examine the impact of the characteristic strength of the concrete (f_{cu}) on the behavior of CFDST stub columns. The compressive strength of concrete specimens, denoted as (f_{cu}), has a range from 50 MPa to 20 MPa. The columns have the same dimensions, as shown in Table (2). The data presented in Figure (3). Illustrates a clear correlation between the characteristic strength of the concrete and the maximum capacity of CFDST stub columns with a circular section. The reduction ratios of the compressive strength of concrete materials are 20%, 40%, and 60%. But, regarding composite members, the peak load experiences a decrease from 1978 KN to 1869 KN, 1736 KN, and 1542 KN, resulting in reduction ratios of 5.5%, 12.2%, and 22%, respectively. Indicating a significant small reduction in capacity as the concrete strength decreases with a big ratio. Furthermore, it is seen that the columns' stiffness in the initial stage remains in close proximity, but the ductility of the specimens increases as the characteristic strength of the concrete decreases.

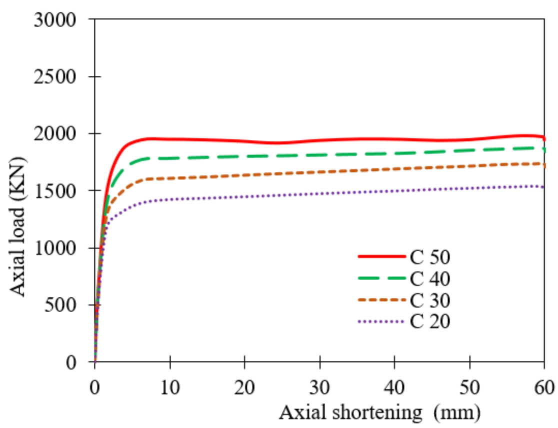

Figure 3. Relationship between load and shortening of C50, C40, C30 and C20

Table 2. Dimensions, material properties and F.E result of the specimens of parametric study

	D (mm)	t_o (mm)	D/t_o	d (mm)	t_i (mm)	d/t_i	f_y (MPa)	L (mm)	f_{cu} (MPa)	$P_{F.E}$ (KN)
C 50	180	4	45	100	2.2	45.5	300	700	50	1978
C 40									40	1869
C 30									30	1736
C 20									20	1542

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V. Conclusions

The behavior of axially comprised stub columns composed of dual circular steel tubes (CFDST) infilled with concrete is examined in this paper. To be able to validate the accuracy of the F.E model, constitutive technique for steel tubes as well as core concrete were employed to evaluate and compare the available test findings. According to the analysis of parameters and comparative research, it is possible to make the following findings.

1- After comparing the test findings, it has been shown that the numerical outcomes derived from the Chang model [14] exhibit a favorable level of concurrence with the experimental results.
2- The capacity of CFDST columns exhibits a positive correlation as the characteristic strength of concrete increases. However, it should be noted that this gain in strength has to be paired with a significant decrease in ductility.
3- The enhancement of steel material strength outcomes a significant improvement in the bearing capacity of the column, but still preserves the ductility of the column.
4- The impact of the thickness (t_i) of the inner tube on column behavior was found to be less significant compared to that of external tube thickness (t_e). This is explained by the inner tube's reduced the cross-sectional area when compared with the outer tube.

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Conflicts of Interest: There is no conflict of interest, according to the Author understanding.

References

[1] Giakoumelis, Georgios, and Dennis Lam. "Axial capacity of circular concrete-filled tube columns." Journal of constructional steel research 60.7 (2004): 1049-1068.
[2] Lu, Yiyan, et al. "Behavior of steel fiber reinforced concrete-filled steel tube columns under axial compression." Construction and Building Materials 95 (2015): 74-85.
[3] Lai, M. H., and J. C. M. Ho. "A theoretical axial stress-strain model for circular concrete-filled-steel-tube columns." Engineering Structures 125 (2016): 124-143.
[4] Fam, Amir, Frank S. Qie, and Sami Rizkalla. "Concrete-filled steel tubes subjected to axial compression and lateral cyclic loads." Journal of Structural Engineering 130.4 (2004): 631-640.
[5] Kitada, T. "Ultimate strength and ductility of state-of-the-art concrete-filled steel bridge piers in Japan." Engineering structures 20.4-6 (1998): 347-354.
[6] Han, Lin-Hai, Guo-Huang Yao, and Zhong Tao. "Behaviors of concrete-filled steel tubular members subjected to combined loading." Thin-Walled Structures 45.6 (2007): 600-619.
[7] Huang, Chao, et al. "Behavior of concrete-filled steel tubular planar intersecting connections under axial compression, Part 1: Experimental study." Engineering Structures 32.1 (2010): 60-68.
[8] Cai, Jingming, Jinlong Pan, and Yufei Wu. "Mechanical behavior of steel-reinforced concrete-filled steel tubular (SRCFST) columns under uniaxial compressive loading." Thin-Walled Structures 97 (2015): 1-10.
[9] Li, Wei, Lin-Hai Han, and Xiao-Ling Zhao. "Axial strength of concrete-filled double skin steel tubular (CFDST) columns with preload on steel tubes." Thin-walled structures 56 (2012): 9-20.
[10] Ekmekyapar, Talha, and Baraa JM Al-Eliwi. "Concrete filled double circular steel tube (CFDCST) stub columns." Engineering Structures 135 (2017): 68-80.
[11] Fang, X. D., and S. J. Lin. "Axial compressive test of columns with multi barrel tube-confined high performance concrete." Journal of Building structures 35.4 (2014): 236-245.
[12] Wan, Cheng-Yong, and Xiao-Xiong Zha. "Nonlinear analysis and design of concrete-filled dual steel tubular columns under axial loading." Steel and Composite Structures 20.3 (2016): 571-597.
[13] Peng, Y-Y., K-F. Tan, and Y. Yao. "Mechanical properties of duplex steel tube high-strength concrete short columns under axial compression." Wuhan Ligong Daxue Xuebao(Journal of Wuhan University of Technology) 33.2 (2011): 105-109.
[14] Chang, Xu, et al. "Study on concrete-filled stainless steel–carbon steel tubular (CFSCT) stub columns under compression." Thin-Walled Structures 63 (2013): 125-133.
[15] Hassanein, M. F., O. F. Kharoob, and Q. Q. Liang. "Behaviour of circular concrete-filled lean duplex stainless steel–carbon steel tubular short columns." Engineering Structures 56 (2013): 83-94.
[16] Xiong, Ming-Xiang, De-Xin Xiong, and JY Richard Liew. "Axial performance of short concrete filled steel tubes with high-and ultra-high-strength materials." Engineering Structures 136 (2017): 494-510.
[17] Ahmed, Mizan, et al. "Numerical analysis of axially loaded circular high strength concrete-filled double steel tubular short columns." Thin-Walled Structures 138 (2019): 105-116.
[18] Pagoulatou, M., et al. "Finite element analysis on the capacity of circular concrete-filled double-skin steel tubular (CFDST) stub columns." Engineering Structures 72 (2014): 102-112.
[19] Hassanein, M. F., and V. I. Patel. "Round-ended rectangular concrete-filled steel tubular short columns: FE investigation under axial compression." Journal of Constructional Steel Research 140 (2018): 222-236.
[20] Hu, Hsuan-Teh, et al. "Nonlinear analysis of axially loaded concrete-filled tube columns with confinement effect." Journal of Structural Engineering 129.10 (2003): 1322-1329.
[21] Hu, Hsuan-Teh, Chiung-Shiann Huang, and Zhi-Liang Chen. "Finite element analysis of CFT columns subjected to an axial compressive force and bending moment in combination." Journal of Constructional Steel Research 61.12 (2005): 1692-1712.
[22] Tao, Zhong, Zhi-Bin Wang, and Qing Yu. "Finite element modelling of concrete-filled steel stub columns under axial compression." Journal of constructional steel research 89 (2013): 121-131.
[23] Ellobody, Ehab, and Ben Young. "Nonlinear analysis of concrete-filled steel SHS and RHS columns." Thin-walled structures 44.8 (2006): 919-930.
[24] Liang, Qing Quan, and Sam Fragomeni. "Nonlinear analysis of circular concrete-filled steel tubular short columns under axial loading." Journal of Constructional Steel Research 65.12 (2009): 2186-2196.
[25] Hassanein, M. F., et al. "Finite element analysis of large diameter high strength octagonal CFST short columns." Thin-Walled Structures 123 (2018): 467-482.

Doi: 10.21608/ERJENG.2023.236535.1244