Finite element analysis on the structural behaviour of square CFST beams

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Abstract. This paper presents the finite element (FE) analysis and modelling of square concrete-filled steel tube (CFST) members subjected to a flexural load. A parametric study is conducted using the verified FE model to study the effect of the depth-to-thickness (D/t) ratio (18.75, 25, and 30), the compressive strength of infilled concrete (60, 80, and 100 MPa), and the yield strength of the steel tube (410, 500, and 600 MPa) on the flexural behaviour of the square CFST members. Decreasing the D/t ratio (from 30 to 18.75) can significantly increase the ultimate capacity of the square CFST members (up to 25%) while having a marginal effect on the initial stiffness of the CFST members. The ultimate bending capacity of the CFST members increases by up to 55% when the yield strength of the outer steel tube increases from 410 MPa to 600 MPa. However, the flexural capacity increases by only 12% when the compressive strength of the infilled concrete increases from 60 MPa to 100 MPa, hence showing a marginal effect. Results of the parametric studies are used to assess the current design models, and Han’s model predicts the most accurate flexural capacity.

1. Introduction
Several researchers presented different procedures in order to study the effect of both static and dynamic loading on different composite systems [1], [2], [3]. Numerous problems arise while dealing with modelling of composite systems that combine two different materials, ductile steel and brittle concrete. The modelling of such composite sections should capture the relative stiffness of each material properly. Concrete filled steel tube (CFST) is a composite material which is composed of steel tube filled with concrete. The use of CFST columns and beams, in construction of buildings, has been increased exponentially in recent decades [4], [5], [6]. As suggested by structural engineers, the CFST members are the most interesting composite members for several modern building projects [7], [8]. Compared to conventional hollow steel/concrete members, this type of composite member has more advantages; such as high speed of construction work due to the omission of reinforcing bars and framework, low structure cost, conservation of environment, high ductility and strength capacity [9], and also provide a good damping merits and are excellent seismically resistant [10],[11]. Furthermore, different types of concrete including recycled aggregates can be used as an infill in CFST, thus helps in cleaning the environment [12], [13], [14], [15].

Several researchers have investigated the structural behaviour of circular CFST. However, only few studies are available in the literature regarding the numerical analysis on the structural performance of circular CFST. Hu et al., [16] proposed material constitutive model for circular CFST columns subjected to pure bending. They performed finite element analysis (FEA) and validated the theoretical results with the experimental data, and concluded that the concrete acts as ideal material to resist compressive loading in the typical applications, only when the depth-to-thickness (D/t) ratio is greater...
than 74. In addition, the infilled concrete has no significant effect on the strength of CFST columns when the D/t ratio is less than 20.

Lakshmi and Shanmugam [17] proposed a semi-analytical method by using an iterative process, the relationship between moment-curvature-thrust is generated to investigate the behaviour of CFST columns. They considered different cross-sections including square, rectangle and circle of compact section in the FE analysis. The pin-ended columns subjected to bi-axial or uniaxial loads were studied. They verified the theoretical and experimental results and concluded that the moment capacity of columns decreases with an increase in axial load. Whereas, Liang et al. [18] studied the FEM behaviour of simply supported composite beams subjected to combined shear and flexure loading. A 3D FE model was developed to consider the material and geometric non-linear behaviour of composite beams and is verified by experimental results. The verified FE model was then used to study the effects of different factors effecting the combined moment and shear capacities of concrete slab and composite beams. In addition, the effect of the degree of shear connection on the vertical shear strength of deep composite beams loaded in shear was studied. Design models were proposed for vertical shear strength including the contributions from composite action and concrete slab. For the design of simply supported composite beams under combined bending and shear, ultimate moment-shear interaction was proposed. The proposed design models provided economical and consistent design procedure for simply supported composite beams.

Lu and Kennedy [19] examined the effects of different D/t ratio and different shear span to depth ratio on twelve square and rectangular steel beams. They reported that the flexural strength of the CFST is increased by 10-30% over that of hollow steel sections, depending on relative proportions of concrete and steel. The flexural stiffness is also increased due to concrete infill. The shear-span to depth ratio has no significant effect on ultimate strength of CFST. Formulae for the strength of square and rectangular CFST under flexure load were suggested. However, Gho and Liu [20] studied the flexural behaviour of rectangular CFSTs by using high strength steel and concrete. It was concluded that AISC, ACI and EC4 substantially underestimated the flexural strengths of high-strength CFST. Whereas, Elchalakani et al., [21] performed experiments on circular CFSTs subjected to pure bending. They reported that the concrete filling in the steel tubes increases the ductility, energy absorption and strength of thinner sections. Han [22] proposed a model that can predict the structural behaviour of CFST after conducting a series of experiments on CFST beams. Both square and rectangular CFST were tested. The author concluded that the moment capacities of CFST beams predicted by BS5400 (1979), LRFD-ASIC (1999), EC4 (1994) and AIJ (1997) are lower than the experimental values. However, the model is only valid for D=100-2000 mm; $f_{scy}=200-500$ MPa and $f_{ck}=20-80$ MPa and cannot be used for high strength and ultra-high strength concrete. Recently, Zhou, Fan [23] studied the behaviour of CFST under tensile loading. It was observed that the stiffness of hollow steel tube is increased 31.8% by adding concrete infill in hollow steel tube.

As the available literature lacks the numerical model for the flexural behaviour of square and rectangular CFST, therefore, the main aim of this study is to investigate the flexural behaviour of CFST beam numerically by using the commercial FEA package ANSYS [24]. This investigation contains the FEA modelling technique to analyse the flexural behaviour, interaction of concrete and steel and load-deflection curves of different types of steel and concrete for square and rectangular CFST’s under pure bending. FEA model is verified with the experimental results available in the literature. After FEA model verification, the numerical analysis is extended to perform the parametric study like compressive strength of concrete, D/t ratio and yield strength of steel on the performance of CFST beams under flexure load.
2. Details of finite element model

General
The commercial finite element tool ANSYS is used to study the flexural behaviour of the CFST beams. Two basic materials are considered to model the flexural behaviour of CFST beams. Steel is used to model the outer tube while the inner core is defined with concrete material.

Finite element type and boundary conditions
A simply supported hollow-steel beam filled with concrete under two-point loading is used to investigate the flexural behaviour and strength. Mesh independency study has been performed to get optimized mesh with less computational cost. Element type for concrete core and steel tube is selected from element library in ANSYS. Based on the geometric features of steel and concrete, a suitable element type for the analysis is selected. The steel tube part was divided into 1344 elements and 9312 nodes while the concrete model included 13080 elements and 78952 nodes. Accurate boundary conditions have to be applied on the nodes lying on the plane of symmetry, in order to reflect the accurate flexure behaviour. Hinge supports are defined by constraining the nodes in y-direction and allow free to move in X and Z-direction. Both supports are located at the distance of 100 mm from free ends. No imperfection of loading or boundary conditions are taken into consideration.

Materials Modelling
A steel model for structural steel as suggested by Han et al., [25] is used for uni-axial stress-strain relation of steel. In this model, hardening of the structural steel is considered. The deformation of steel includes elastic, elastic-plastic, plastic, hardening and fracture are shown in figure 1. Where \( f_p \), \( f_y \), and \( f_u \) represents the proportional limit, yield, and ultimate strength of steel, at their respective strains, and \( \epsilon_e = 0.8\epsilon_{e1}, \frac{f_y}{E_s}, \frac{\epsilon_e}{\epsilon_{e1}} = 1.5\epsilon_e, \frac{\epsilon_{e2}}{\epsilon_{e1}} = 100\epsilon_{e1}, \frac{\epsilon_{e3}}{\epsilon_{e1}} = 100\epsilon_{e1} \).

![Figure 1. Schematic sketch of uniaxial stress–strain relation for steel [25]](image)

The Von-Mises yield function with associated plastic flow is used in multi axial stress states. The structural steel is assumed to have isotropic hardening behaviour, so that yield stresses increase or decrease in all stress direction when plastic straining occurs. When the Mises stress reaches the yield stress of the steel, stress can still increase when subjected to further plastic straining, because there is a hardening stage in the stress-strain relationship. The modulus of elasticity and the Poisson’s ratio for the steel are taken as 2x10^5 N/mm2 and 0.3, respectively. Poisson’s ratio of concrete under flexural stresses is in the range of 0.15-0.22, with a representative value of 0.20. Table 1 shows the material properties of steel and concrete used in the analysis.
Table 1. Material Properties of steel and concrete

| Materials | Dimension of section (mm) | Yield stress ($f_y$), (MPa) | Ultimate stress ($f_u$), (MPa) | Modulus of elasticity (E), (MPa) | Poisson’s Ratio |
|-----------|---------------------------|-----------------------------|-----------------------------|-----------------------------|----------------|
| Steel     | 72 x 72 x 3.2             | 345                         | 510                         | $2.1 \times 10^5$          | 0.3            |
| Concrete  | 65.6 x 65.6               | 32.3                        | -                           | $2.842 \times 10^4$        | 0.2            |

3. Model verification
The accuracy and efficiency of the developed FE model are demonstrated through the comparisons between the FE and experimental results with different parameters as performed by Soundararajan and Shanmugasundaram [26]. The ultimate flexure load, moment-curvature curves and load-deflection curves of CFST beams are considered in the verification of the FE model developed. The details of the experimental setup and the boundary conditions in the FE model are shown in figure 2 and 3, respectively.

![Figure 2. The details of the experimental test setup [26]](image)

![Figure 3. Boundary conditions and Cross-section of the modelled beam](image)
4. Ultimate Strengths of CFST beams
The geometry, material properties and experimental results of CFST beams tested by Soundararajan and Shanmugasundaram [26] are mentioned in table 2. The dimensions of steel tube are kept constant in all experiments. The specimens were made of normal mix concrete (NMC), Fly-ash concrete (FAC), quarry waste concrete (QWC) and low-strength concrete (LSC). The depth-to-thickness ratio of the steel tube was kept as 20.5. All Specimens were tested under the two-point flexure loads. CFST beams were constructed using concrete of strengths in the range of 21 MPa to 32.6 MPa. The yield strength of steel tubes was 345 MPa while the ultimate stress was 510 MPa as shown in table 1.

Table 2. Geometry, Material properties and Ultimate moment of tested specimen

| Specimen designation | Dimensions (mm) | Area of steel, $A_s$ (mm$^2$) | Area of concrete, $A_c$ (mm$^2$) | Types of filled concretes | Compressive strength of concrete (MPa) | Average ultimate moment |
|----------------------|----------------|-----------------------------|-----------------------------|--------------------------|--------------------------------------|------------------------|
| NMC                  | 72 x 72 x 3.2  | 881                         | 4303                        | Normal Mix concrete      | 32.6                                 | 10.01                  |
| FAC                  | 72 x 72 x 3.2  | 881                         | 4303                        | Fly Ash Concrete         | 32.5                                 | 10.12                  |
| QWC                  | 72 x 72 x 3.2  | 881                         | 4303                        | Quarry Waste Concrete    | 21.63                                | 9.99                   |

Table 3. Ultimate Flexure Moment

| Specimen Designation | $P_{e,exp}$ (kN) | Average, $P_c$ (kN) | $P_{e,fe}$ (kN) | $M_{u,exp}$ (kN-m) | Average ultimate moment exp. (kN-m) | Ultimate Moment FE (kN-m) | $M_{u,Num}/M_{u,exp}$ |
|----------------------|-----------------|---------------------|----------------|--------------------|-----------------------------------|--------------------------|------------------------|
| NMC-1                | 61              | 60.67               | 61             | 10.06              | 10.01                             | 10.07                    | 1.005                  |
| NMC-2                | 58              | 60.67               | 61             | 9.57               | 10.01                             | 10.07                    | 0.994                  |
| NMC-3                | 63              | 60.67               | 61             | 10.40              | 10.12                             | 10.07                    | 0.994                  |
| FAC-1                | 60              | 61.33               | 61             | 9.90               | 9.74                              | 9.73                     | 0.974                  |
| FAC-2                | 61              | 61.33               | 61             | 10.07              | 10.12                             | 10.07                    | 0.994                  |
| FAC-3                | 63              | 61.33               | 61             | 10.40              | 10.12                             | 10.07                    | 0.994                  |
| QWC-1                | 59              | 60.33               | 59             | 9.74               | 9.99                              | 9.73                     | 0.974                  |
| QWC-2                | 60              | 60.33               | 59             | 10.00              | 9.99                              | 9.73                     | 0.974                  |
| QWC-3                | 62              | 60.33               | 59             | 10.23              |                                    |                          |                        |

Table 3 shows the experimental and computational ultimate flexure strengths of CFST beams. Where $P_{e,exp}$ denotes the experimental ultimate flexure strength and $P_{e,fe}$ represents the ultimate flexure strength predicted by the FE model. It can be seen from table 3 that the predicted ultimate flexure strengths of tested specimen are in good agreement with experimental results. The mean ultimate flexure strength predicted by the numerical model is 1.01 times the experimental value with a standard deviation of 0.016 and a coefficient of variation of 0.016.
5. Load-deflection curves
The load-deflection curves for CFST beams predicted by FE model were compared with the experimental results provided by [26]. The load-deflection curves for NMC predicted by FE model and obtained from the experiments are shown in figure 4. It can be observed that the load-deflection curve predicted by the numerical model is in good agreement with the experimental results. The difference between the experimental and numerical ultimate flexure load is only 3%. Whereas, figure 5 gives the predicted and experimental axial load-deflection curves for the specimens of QWC concrete as tested by the same author. It can be seen that the numerical model predicts very good relationship of the load-deflection curve for the tested specimen up to the ultimate flexure load. However, the computed ultimate load is slightly higher than the experimental value due to the uncertainty of the initial imperfections and material properties.

**Figure 4. Load-Deflection Curve for NMC**

**Figure 5. Load-Deflection curve for Quarry Waste Concrete (QWC)**
6. Parametric Study
An extensive parametric study was performed to investigate the influences of depth-to-thickness ratio, concrete compressive strengths and steel yield strengths on the fundamental behavior of CFSR beams under flexure load only. Only one variable was considered at a time to assess its individual effect. Three different concrete strengths with a range of steel yield strength and D/t ratio were selected that represent CFST members currently used in Malaysia.

6.1 Effect of Depth-to-thickness ratio
The strength of CFST beams depends on depth-to-thickness ratio (D/t). The FE was used to examine the effects of D/t ratio on the ultimate moment/load capacity and load deflection curves of CFST beams. The dimensions of the beams for the analysis were selected as a cross-section of 80 x 80 mm and length of 1200 mm. The D/t ratios of the beam sections were calculated as 18.75, 25 and 30 by changing the thickness of steel tubes. The yield and tensile strengths of steel tubes were 345 MPa and 510 MPa, respectively, and the modulus of elasticity was about 200 GPa. Whereas, the compressive strength and modulus of elasticity of the in-filled concrete was about 30 MPa and 29000 MPa, respectively.

The influence of D/t ratio on the flexure load-deflection curves for CFST beams are illustrated in figure 6. As can be seen in the figure 6 that by increasing the D/t ratio of the CFST beams have slightly reduces their initial stiffness. However, increasing the D/t ratio significantly reduces the ultimate flexure load carrying capacity of CFST beams. This is attributed to the fact that the beam having larger D/t ratio has a lesser area of steel and it may have undergone local buckling which reduces the ultimate load carrying capacity of the beam. Similar conclusions were drawn by different author Chen and Wang [27], after performing experiments on thin-walled walled dodecagonal section double skin CFST [27] and circular CFST [28] under bending.

![Figure 6. Load-deflection curve of different D/t ratio](image)

6.2 Effect of grade of concrete
The effect of compressive strengths on the ultimate capacity and behaviour of CFST beams were studied by the FE Model. In the parametric study, the compressive strength of concrete was varied from 60 to 100 MPa. Both depth and width of the steel tube was placed constant as 80 mm. The steel tube wall was 2.5 mm thick, so that its D/t ratio was 30. The steel yield and ultimate strengths were 345 and 510 MPa, respectively, and the modulus of elasticity was 200 GPa.
The flexure load-deflection curves for CFST beams with different concrete strengths are shown in figure 7. As can be seen in figure 7 that the ultimate flexure strengths of square CFST beams does not increase significantly with an increase in the compressive strength of concrete. However, by increasing the compressive strength of concrete from 60 to 80 MPa and 100 MPa, the ultimate flexural strength was increased by about 4% and 12%, respectively. Figure 7 also describes that the increase in the compressive strength of concrete resulted in very low improvement in the initial stiffness of the square CFST beams. Similar observations were made by a number of researchers after conducting experimental study on the behaviour of ultra-high strength square CFST [29] and for circular CFST [28] under flexural load.

![Figure 7. Load-deflection curve for different compressive strengths of concrete](image)

### 6.3 Influences of steel yield strengths

The square CFSR beams with different steel yield strengths and a cross-section of 80 x 80 mm with same D/t ratio of about 25 were analysed using the FE model. The yield strengths of the steel tubes were 410 MPa, 500 MPa, and 600 MPa the corresponding ultimate strengths were 520 MPa, 590 MPa and 690 MPa, respectively. The Young's modulus of steel was 200 GPa. The steel tubes were infilled with 60 MPa concrete have modulus of elasticity of 32600 MPa.

![Figure 8. Load-deflection curve for different types of steel](image)
Figure 8 illustrates the influences of steel yield strengths on the flexure load deflection curves of square CFST beams. It can be observed from the figure 8 that the yield strength of steel does not have an effect of the initial stiffness of beams. However, the ultimate flexure strength of square CFST beams is found to increase significantly with an increase in the yield strength of steel. By increasing the yield strength of steel from 410 MPa to 500 MPa and 600 MPa, the ultimate flexure load of the square CFST beam is found to increase by 22% and 55% respectively. Similar conclusions were drawn by Duarte et al., [30] for rubberized CFST members.

7. Comparison of moment capacities with design codes

7.1 Eurocode
As mentioned in Eurocode [31], the ultimate capacity of CFST columns subjected to combined bending and compression is determined from an interaction curve. An interaction curve between moment and axial compression can be obtained for column by assuming several possible positions of neutral axis with the cross-section, and determining the moments and internal forces from the resulting plastic stress blocks. In the absence of axial load and steel reinforcement in CFST, the equation for moment becomes.

\[ M_{pl,Rd} = f_{yd} (W_{pa} - W_{pan}) + 0.5 f_{cd} (W_{pc} - W_{pcn}) \]  (1)

\[ W_{pc} = \frac{(b - 2t)(h - 2t)^2}{4} \]  (2)

\[ h_n = \frac{A_2 f_{cd} - A_{psn}(2f_{yd} - f_{cd})}{2bf_{yd} + 4t(2f_{yd} - f_{cd})} \]  (3)

\[ W_{pan} = 2h_n^2 \]  (4)

\[ W_{pcn} = (b - 2t)h_n^2 - W_{psn} \]  (5)

Where, \( h_n \) is the distance from compression region to the center line of the CFST cross-section, \( W_{pc} \) and \( W_{pa} \) are the plastic section modulus for concrete and steel respectively \( W_{pan} \) and \( W_{pcn} \) are the plastic section modulus of the corresponding components within the region of 2hn from the centre-line of the composite cross-section.

As seen in table 4, Eurocode design rules give mean, standard deviation and Co-efficient of Variation (COV) values of 0.73, 0.08 and 0.12 and are conservative. However, it predicts the moment capacity more accurately than AISC-LRFD and CIDECT design rules.

7.2 AISC-LRFD
The flexural strength of CFST beams and columns according to LRFD [32] were calculated based only on the steel hollow section. The Plastic moment capacity of a CFST beam may be evaluated as;

\[ M = Z f_y \]  (6)

where, \( Z \) is he plastic section modulus and \( f_y \) is the yield strength of steel tube.

As shown in table 4, AISC-LRFD design rules give mean, standard deviation and COV values of 0.65, 0.08 and 0.13 and are most conservative.

7.3 CIDECT
The Ultimate moment capacity for CFST beams according to the CIDECT [33] can be defined as;

\[ M_{u,CIDECT} = M_{ratio} \frac{D^2 B - (b - 2t)^2(b - 2t)}{4} f_y \]  (7)

where, \( M_{ratio} \) is a ratio of the baring capacity of composite hollow section to that of the hollow section, \( D, t \) and \( B \) is the depth, thickness and width of composite section respectively, \( f_y \) is the yield stress.

CIDECT design rules give mean, standard deviation and COV values of 0.72, 0.08 and 0.11, respectively, and the values are conservative, as can be seen in table 4.
7.4 Han (2004) model

According to Han [22], the ultimate moment capacity of the CFST beam is given by:

\[ M_u = \gamma_m f_{scy} W_{scm} \]  
\[ f_{scy} = (1.18 + 0.85\xi) f_{ck} \]  
\[ W_{scm} = \frac{B^3}{6} \]  
\[ \xi = \frac{A_s f_y}{A_c f_{ck}} \]  
\[ \gamma_m = 1.04 + 0.48 \ln(\xi + 0.1) \]  

where, \( M_u \) is the moment capacity of the CFST beam, \( f_{scy} \) is the nominal yielding strength of the steel tube, \( W_{scm} \) is the section modulus of CFST cross-section, \( \xi \) is the constraining factor, and \( \gamma_m \) is the flexural strength index. However, Han model is only valid for \( D=100-2000 \) mm; \( f_{scy}=200-500 \) MPa and \( f_{ck}=20-80 \) MPa and cannot be used for ultra-high strength concrete.

The mean, standard deviation, COV and capacity reduction factors of the ratio of moment capacities from FE model and HAN model are shown in table 4. Han Model values are the best in comparison to all codes with its overall mean, standard deviation and COV values of 0.80, 0.08 and 0.10, respectively.

**Table 4. Comparisons of Results from different codes and FEA**

| Cross Section | Thickness | Yield Strength | Compressive Strength | Euro Code Factor | AISC Factor | CIDECT Factor | Han Factor | FEA Results |
|---------------|-----------|----------------|----------------------|------------------|-------------|--------------|-------------|-------------|
| 80 x 80       | 3         | 410            | 60                   | 11.86            | 0.80        | 10.57        | 0.71        | 11.83       | 0.80        | 13.11       | 0.88        | 14.85       |
| 80 x 80       | 3         | 500            | 60                   | 14.27            | 0.79        | 12.89        | 0.71        | 14.23       | 0.78        | 15.55       | 0.86        | 18.15       |
| 80 x 80       | 3         | 600            | 60                   | 16.93            | 0.73        | 15.47        | 0.67        | 16.83       | 0.73        | 18.27       | 0.79        | 23.10       |
| 80 x 80       | 2.5       | 345            | 60                   | 8.68             | 0.66        | 7.56         | 0.57        | 8.55        | 0.65        | 9.59        | 0.73        | 13.20       |
| 80 x 80       | 2.5       | 345            | 80                   | 8.62             | 0.65        | 7.56         | 0.57        | 8.70        | 0.66        | 10.20       | 0.77        | 13.20       |
| 80 x 80       | 2.5       | 345            | 80                   | 8.52             | 0.57        | 7.56         | 0.51        | 8.78        | 0.59        | 10.73       | 0.72        | 14.85       |
| 80 x 80       | 2.5       | 345            | 100                  | 8.52             | 0.57        | 7.56         | 0.51        | 8.78        | 0.59        | 10.73       | 0.72        | 14.85       |
| 80 x 80       | 2.5       | 345            | 30                   | 8.64             | 0.75        | 7.56         | 0.65        | 8.27        | 0.72        | 8.58        | 0.74        | 11.55       |
| 80 x 80       | 3         | 345            | 30                   | 10.00            | 0.76        | 8.89         | 0.67        | 9.61        | 0.73        | 10.37       | 0.79        | 13.20       |
| 80 x 80       | 4         | 345            | 30                   | 12.54            | 0.84        | 11.41        | 0.77        | 12.19       | 0.82        | 14.33       | 0.96        | 14.85       |

Mean: 0.73  SD: 0.08  COV: 0.12

8. Conclusions

The verification and applications of a three-dimensional finite element model developed for the non-linear analysis of CFST square beams at ambient temperature have been presented in this paper. The finite element model was verified by comparisons of computational solutions with experimental results present in [26] for three different types of concrete. It has been shown that the load-deflection curves and ultimate flexure load capacity of square CFST beams predicted by the numerical model are generally in good agreement with the experiential results. Therefore, the verified numerical model was used for parametric studies to investigate the effects of D/t ratio, yield strength of steel and compressive strength of concrete on the load-deflection curves and ultimate flexure load carrying capacity of CFST beams under flexure load.
This paper provided new FE results on the basic behaviour of square CFST beams filled with concrete with different parameters including depth-to-thickness ratio, concrete compressive strengths and steel yield strengths. The study concluded that depth-to-thickness of steel tube has significant impact on the performance of the CFST beams. It is also observed that compressive strength of concrete and yield strength of steel used in CFST beams, have very marginal effect on the structural behaviour of CFST. The FE results presented can be used for the verification of other nonlinear analysis techniques and to modify composite design codes for square CFST beams. Furthermore, the FE model developed can be used in the design and analysis of high strength concrete subjected to flexure load in practice. In addition, it can assist in generating the required data needed to develop design recommendations for CFST members with fewer limitations imposed.

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