Numerical Investigation of Concrete Filled Steel Tubular Beams

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ABSTRACT

Concrete-filled steel tubular (CFST) structure offers numerous structural benefits, and has been widely used in Civil Engineering structures. CFST's advantages over RCC in terms of load bearing, ductility, and flexural strength, make it a promising option in structural applications. The concrete-filled steel tubular structure can be treated as an alternative system to the steel or the reinforced concrete system. With the rapid development of research and application of concrete filled steel tubular structures all over the world in the past decades, the scope of "concrete-filled steel tube" has been extended greatly by researchers and engineers. Numerical investigation on the performance of CFST beams by varying the shape (Rectangular, Square), grade of infilled concrete (M25, M30), and the thickness of steel tube (8mm, 10mm, 12mm) using ANSYS software are conducted in the present study. Rectangular cross-sections provided significantly higher flexural rigidity compared to square cross-sections, making them more suitable for applications requiring higher stiffness. Higher concrete grade improved flexural rigidity, but the improvement is relatively small. Increasing thickness of steel tube improved flexural rigidity, but the relative benefit of using higher-grade concrete diminished as thickness increases.

Keywords: CFST, ANSYS, concrete, steel

1 Introduction

Concrete-Filled Steel Tubular (CFST) structures are composite members consisting of a steel tube filled with concrete, combining the advantages of both materials to achieve superior structural performance. The steel tube provides confinement to the concrete, enhancing its compressive strength and ductility, while the concrete core prevents local buckling of the steel tube, improving load-bearing capacity and stability. Concrete-filled steel tubes have been increasingly used in the construction industry due to their favourable structural performance. The concrete-filled steel tubular structure offers numerous structural benefits, including high strength [1], [2] and fire resistances [3] - [5], favourable ductility [6], [7], and large energy absorption capacities [8]. There is also no need for the use of shuttering during concrete construction; hence, the construction cost and time are reduced [9], [10]. These advantages have been widely exploited and have led to the extensive use of concrete filled tubular structures in civil engineering structures. It is well established that the compressive strength of concrete is much higher than its tensile strength [1], [9], [11]. Furthermore, the compressive strength is enhanced under bi-axial or tri-axial restraint. For the structural steel, the tensile strength is high while the shape may buckle locally under compression. In concrete-filled steel tubular members, steel and concrete are used such that their natural and most prominent characteristics are taken advantage of [1], [12]. The confinement of concrete is provided by the steel tube, and the local buckling of the steel tube is improved due to the support of the concrete core.

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CFST members have superior structural performance than equivalent conventional Reinforced Concrete (RC) and hollow steel tube members. CFST members can be designed with a reduced section size to achieve the same structural capacity. The superior performance is attributed to the composite action between concrete and steel. The confining effect of the outer tube can significantly enhance the strength of the infill concrete. The circular cross section provides the strongest confinement to the core concrete, and the local buckling is more likely to occur in square or rectangular cross-sections. However, the concrete-filled steel tubes with square and rectangular cross-sections are still increasingly used in construction, for the reasons of being easier in beam-to-column connection design, high cross-sectional bending stiffness and for aesthetic reasons [13].

CFST beams are widely used in various structural applications due to their superior performance and versatility. In bridge construction, CFST beams are commonly used in girders and piers for long-span bridges, where their high load-bearing capacity and durability are essential [6], [12]. In high-rise buildings, CFST beams are applied in composite floor systems and transfer beams, providing the necessary strength and stability to support the structure [9], [10]. Industrial structures, such as warehouses and factories, also benefit from the use of CFST beams due to their high strength and durability, which make them capable of supporting heavy machinery and equipment [2], [11]. One of the most significant applications of CFST beams is in seismic-resistant structures [7], [8]. Their high ductility and energy absorption capacity make them ideal for use in earthquake-prone regions, where structures must withstand significant lateral forces. The ability of CFST beams to dissipate energy during seismic events helps prevent sudden structural failure, ensuring the safety of occupants and reducing damage to the structure. Overall, the versatility and superior performance of CFST beams make them a preferred choice for a wide range of structural applications, from bridges and high-rise buildings to industrial structures and seismic-resistant designs.

The performance of CFST structures is governed by material selection, geometric design, loading conditions, and environmental exposure. The versatility and performance benefits of CFST structures have made them a preferred choice in modern engineering, with ongoing research optimizing their design for various loading and environmental conditions. The objectives of the present work is to study the performance of CFST beams by varying beam cross sectional shapes (Rectangular [200mm × 450mm], Square [300mm × 300mm]) keeping the cross-sectional area constant, grade of infilled concrete (M25 and M30), and thickness of the steel tube (8mm, 10mm and 12mm).

2 Numerical Study

2.1 General

In the present study, the performance of CFST beams were studied by varying the cross-sectional shape of beams, grade of infilled concrete, and thickness of steel tube. All the beam specimens had a span of 4m with fixed ends and were subjected to a uniformly distributed load of 18.75kN/m. Fe 250 grade steel was used for the study. The numerical analysis was performed in the ANSYS software. The variables considered are: Beam cross sectional shapes - Rectangular (200mm × 450mm) & Square (300mm × 300mm), Grade of in-filled concrete - M25 and M30, and Thickness of the steel tube - 8mm, 10mm and 12mm.

2.2 Model Specification

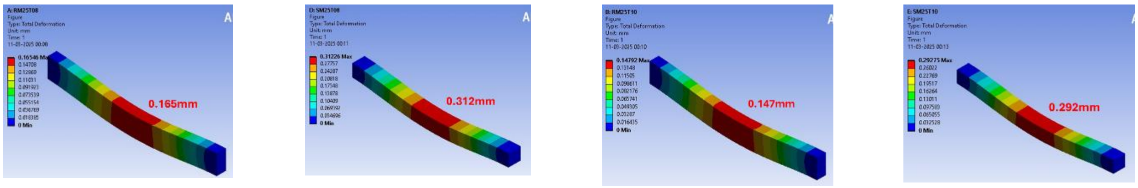
Table 1 shows the model designation details of all the beam specimens.

Table 1: *Model designation*

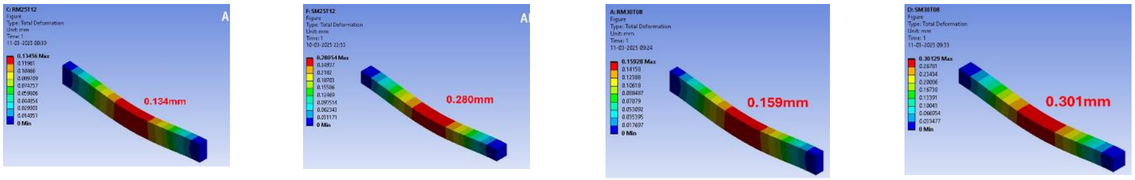
Model Designation	**Beam Cross-section**	**Grade of Infill Concrete**	**Thickness of Steel Tube (mm)**
RM25T08	Rectangle	M25	08
RM25T10	Rectangle	M25	10
RM25T12	Rectangle	M25	12
RM30T08	Rectangle	M30	08
RM30T10	Rectangle	M30	10
RM30T12	Rectangle	M30	12
SM25T08	Square	M25	08
SM25T10	Square	M25	10
SM25T12	Square	M25	12
SM30T08	Square	M30	08
SM30T10	Square	M30	10
SM30T12	Square	M30	12

2.3 Numerical Analysis of CFST Beam Models

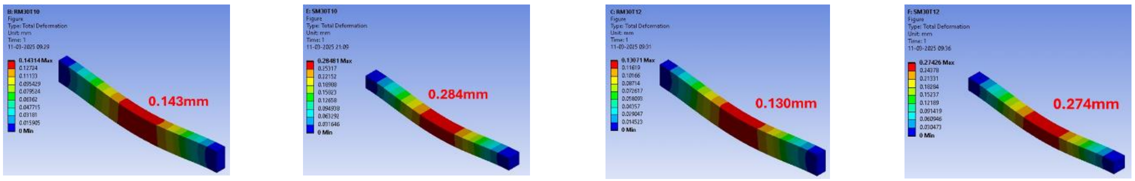
The beam specimens were modelled in Static Structural module of ANSYS software. Frictional contact was assumed between the steel tube and the infilled concrete with a friction coefficient of 0.25. A mesh size of 40 mm was used for the analysis. Number of nodes and elements depends on the surface geometry of each model. The elements used for the present study were SOLID186, CONTA174, and TARGE170. Figure 1 shows the total deformation obtained for CFST beam models.



(a) RM25T08 (b) SM25T08 (c) RM25T10 (d) SM25T10



(e) RM25T12 (f) SM25T12 (g) RM30T08 (h) SM30T08



(i) RM30T10 (j) SM30T10 (k) RM30T12 (l) SM30T12

Figure 1: Total deformation of CFST beam models

3 Results and Discussion

The numerical results of the CFST beam models were compared with the deformation of a traditional RCC beam having the similar cross-sectional dimensions and span. Comparison of the numerical results of CFST beams with the analytical results of RCC beams are tabulated in Table 2. The % reduction indicates how much the numerical result deviates from the analytical result. To understand the effect of various parameters (beam cross sectional shape, grade of infilled concrete, and thickness of steel tube) on the performance of CFST beams, the flexural rigidity of the beam specimens was evaluated.

Table 2: *Numerical analysis results*

Sl. No.	**Model Designation**	**Total Deformation (mm)**		**% Reduction**
		Numerical result (CFST)	**Analytical result (RCC)**	
1	RM25T08	0.16546	0.32922	49.74
2	RM25T10	0.14792	0.32922	55.07
3	RM25T12	0.13456	0.32922	59.13
4	RM30T08	0.15928	0.30053	47.00
5	RM30T10	0.14314	0.30053	52.37
6	RM30T12	0.13071	0.30053	56.51
7	SM25T08	0.31226	0.74074	57.84
8	SM25T10	0.29275	0.74074	60.48
9	SM25T12	0.28054	0.74074	62.13
10	SM30T08	0.30129	0.67620	55.44
11	SM30T10	0.28481	0.67620	57.88
12	SM30T12	0.27426	0.67620	59.44

3.1 Effect of Cross Section on the Performance of CFST Beams

The total deformation values of the rectangular CFST beam models are less than the total deformation values of the corresponding square CFST beam models. This is due to the reduction of the section modulus of the square beam models by 33.33% from that of the rectangular beam models. In all cases, the numerical results show lower total deformation compared to the analytical results. The square CFST beam models show significantly higher % reduction values compared to the rectangular CFST beam models. The square beam models showed a reduction of 47 – 52% in the value of flexural rigidity compared to that of rectangular beam models as shown in Table 3. This was due to the reduction in the value of moment of inertia (55%) of the square section compared to that of rectangular section. This is because the mass in a square section is distributed more evenly around the centroid, whereas in a rectangular section, the mass is distributed farther from the centroid along the longer dimension, increasing its resistance to bending.

Table 3: *Effect of cross section on the performance of CFST beams*

Grade of Concrete	**Thickness (mm)**	**Flexural Rigidity (kNm^2)**		**% Reduction**
		Rectangle	**Square**	
M25	08	75547.0	40030.7	47.0
	10	84505.1	42698.5	49.5
	12	92895.4	44556.9	52.0
M30	08	78478.2	41488.3	47.1
	10	87327.1	43888.9	49.7
	12	95631.6	45577.2	52.3

It suggests that the square section is significantly less resistant to bending compared to the rectangular section and could lead to greater deflection or lower stiffness. Rectangular cross-sections exhibit significantly higher flexural rigidity compared to square cross-sections for the same thickness. This trend holds true across all thicknesses, highlighting that rectangular sections are inherently stiffer than square sections for CFST beams.

3.2 Effect of Grade of Concrete on the Performance of CFST Beams

The grade of concrete also influences the results, but the effect is less pronounced compared to thickness and cross section. The Table 4 illustrates the effect of the grade of concrete on the performance of CFST beams, specifically focusing on flexural rigidity for different cross-sections (rectangle and square) and thicknesses (8 mm, 10 mm, and 12 mm). Increasing the concrete grade from M25 to M30 results in a consistent but modest increase in flexural rigidity for both rectangular and square cross-sections. The percentage increase in flexural rigidity ranges from 2.3% to 3.9%, indicating that higher-grade concrete improves the stiffness of the CFST beams, though the improvement is relatively small. The percentage increase in flexural rigidity with thickness is slightly lower for M30 compared to M25. This suggests that the benefit of increasing thickness is marginally reduced when using higher-grade concrete.

Table 4: *Effect of grade of concrete on the performance of CFST beams*

Cross-section	**Thickness (mm)**	**Flexural Rigidity (kNm^2)**		**% Increase**
		M25	**M30**	
Rectangle	08	75547.0	78478.2	3.9
	10	84505.1	87327.1	3.3
	12	92895.4	95631.6	2.9
Square	08	40030.7	41488.3	3.6
	10	42698.5	43888.9	2.8
	12	44556.9	45577.2	2.3

3.3 Effect of Thickness of Steel Tube on the Performance of CFST Beams

For both rectangular and square models, as the thickness increases, the % reduction in deformation increases. Table 5 shows the percentage increase in flexural rigidity when the thickness is increased from 8 mm to 10 mm and from 10 mm to 12 mm. As the thickness of the steel tube increases, the flexural rigidity also increases for both rectangular and square cross-sections. However, the percentage increase in flexural rigidity when moving from M25 to M30 decreases slightly as the thickness increases. The percentage increase in flexural rigidity is higher when moving from 8 mm to 10 mm compared to moving from 10 mm to 12 mm. This indicates diminishing returns as thickness increases.

Table 5: *Effect of thickness of steel tube on the performance of CFST beams*

Cross-section	**Grade of Concrete**	**% Increase in Flexural Rigidity**	
		8mm to 10mm	**10mm to 12mm**
Rectangle	M25	11.9	9.9
	M30	11.3	9.5
Square	M25	6.7	4.4
	M30	5.8	3.8

4 Conclusion

In the present study, the performance of CFST beams by varying beam cross sectional shapes (Rectangular [200mm × 450mm], Square [300mm × 300mm]) keeping the cross-sectional area constant, grade of infilled concrete (M25 and M30), and thickness of the steel tube (8mm, 10mm and 12mm) are carried out in ANSYS software. CFST beams consistently showed lower deformation than RCC beams, with reductions ranging from 47% to 62%. This suggests that CFST beams are significantly stiffer and more resistant to deformation under the same loading conditions. Square beams deformed significantly more than rectangular beams in both CFST and RCC. This implies that the rectangular beams are structurally more efficient than square beams in resisting deformation. Increasing steel tube thickness improved the performance in CFST beams. Rectangular beams have significantly higher flexural rigidity than square beams. Reduction of flexural rigidity in square beams ranges from 47% to 52.3%, indicates that the square beams are about half as stiff as rectangular beams. M30 beams have slightly higher flexural rigidity than M25, but the difference is marginal (~3-4%). So the concrete grade does not significantly affect the relative performance of beams. Increasing the steel tube thickness improves the flexural rigidity of beams. Percentage reduction increases slightly with thickness (47% → 52%), indicating rectangular beams benefit more from increased thickness than square beams. By increasing flexural rigidity, beams can resist higher loads, control deflection, and avoid failure due to excessive stress.

5 Conflict of Interest

The authors do not have any conflict of interests.

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