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Influence of Section Geometry, Concrete Grade, and Steel Tube Properties on CFST Column Behavior: A review and future scope

Pruthvi Parmar[1], Dr. Major C.S. Sanghvi[2], Prof. Deepa Raval[3]

[1]P. G. Student ,[2]Head of Department, [2]Professor, [3]Assistant Professor
[1,2,3]Department of Applied Mechanics
[1,2,3]L. D. College of Engineering, Ahmedabad, India

Corresponding Author Email: Pruthviparmar053@email.com

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Abstract

High-rise building is increasingly using Concrete-Filled Steel Tube (CFST) columns because of their exceptional strength, ductility, and affordability. This review critically investigates how CFST performance and implementation in tall structures are affected by section geometry, concrete grade, steel grade, and tube thickness. The highest ductility and confinement are found in circular sections, while slightly lower confinement is found in square, rectangular, and polygonal sections, which offer constructability benefits. Confinement is most beneficial for Normal Strength Concrete, but High and Ultra-High Strength Concretes improve axial capacity but decrease post-peak ductility. For stability, local buckling prevention, and composite action optimization, steel quality and tube thickness are essential. In addition to improving cost effectiveness, drift control, and seismic performance, CFST systems also show robustness under high loads. Despite these benefits, there are still unanswered questions about dynamic load behavior, high-strength materials, special-shaped sections, and codification. Thus, CFST columns offer a robust and effective substitute for tall structures, striking a balance between economics and structural performance.

Keywords: Concrete-Filled Steel Tube (CFST), Section shape effect, Effect of Concrete Grade, Steel grade and tube thickness, Seismic performance.

I. INTRODUCTION

Concrete-Filled Steel Tube (CFST) columns have emerged as an efficient structural solution for modern high-rise buildings due to their superior strength, stiffness, ductility, and fire resistance. This system combines two complementary materials: the steel tube provides high tensile strength and effective confinement to the concrete core, while the concrete delays local buckling of the steel tube and enhances overall load-bearing capacity. The resulting composite action enables CFST columns to outperform conventional reinforced concrete (RCC) or steel columns, particularly under demanding conditions such as seismic events, impact, and fire [1–4].

CFSTs are especially advantageous in seismic regions, where ductility and energy absorption are critical. Circular sections provide excellent confinement, delaying local buckling and improving post-peak performance [4,9,10]. Square and rectangular sections, while less efficient in confinement, offer increased stiffness and effective drift control, making them suitable for moment-resisting frames [1,3,17]. Polygonal and special-shaped sections have been investigated to balance structural efficiency with architectural flexibility [12,20,21].

The performance of CFSTs is strongly influenced by concrete grade and steel tube properties. Normal Strength Concrete (NSC) benefits most from confinement, exhibiting ductile post-peak behavior [11]. High Strength Concrete (HSC) enhances axial capacity but reduces ductility due to brittle failure, while Ultra-High Strength Concrete (UHSC) further increases strength yet limits post-peak deformation, particularly in thin-walled tubes [9,13,15,18,19]. Tube thickness and steel grade also play a critical role: thicker tubes with low diameter-to-thickness ratios improve confinement and stability, whereas high-strength steel can increase load capacity but may cause premature local buckling if tube walls are thin [4,10,15,16,22].

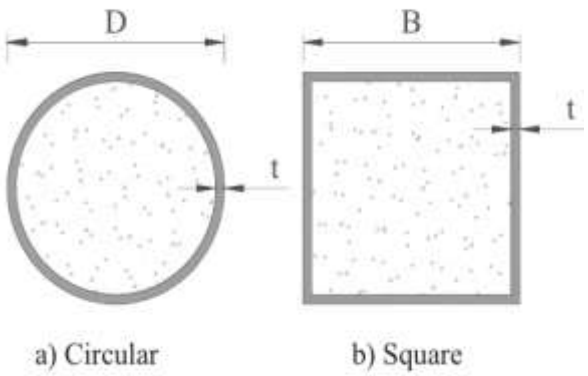

Fig.1 CFST Sections: a) Circular, b) Square

In practice, CFST columns improve seismic performance by reducing natural periods, lateral displacements, and inter-story drifts, while offering economic benefits through reduced steel consumption and smaller member sizes, with reported savings of up to 39% [1–3,8]. Experimental studies confirm their energy absorption under impact and blast loads, highlighting resilience in extreme conditions. Despite these advantages, research gaps remain in codification, special-shaped sections, long-term effects, and dynamic responses, which must be addressed to optimize the design and safe application of CFST systems in high-rise and critical infrastructure projects.

II. EFFECT OF SECTION SHAPE

The cross-sectional geometry of Concrete-Filled Steel Tube (CFST) columns significantly governs their load-carrying behavior, confinement efficiency, and ductility. The geometry not only influences local buckling resistance of the steel tube but also determines how effectively the concrete core is confined under axial and lateral loads.

Circular Sections: Circular CFSTs are widely recognized for their superior confinement capability, providing uniform lateral pressure around the concrete core. This uniform stress distribution enhances ductility and axial strength, making circular CFSTs highly effective under both monotonic and cyclic loads [4,9,10]. Experimental studies by Giakoumelis and Lam [4] and Ellobody et al. [9] demonstrated that circular sections delay local buckling, utilize both normal and high-strength concrete effectively, and exhibit superior post-peak load resistance. Their performance in seismic conditions is especially noteworthy, with improved energy absorption and reduced brittle failure [10].

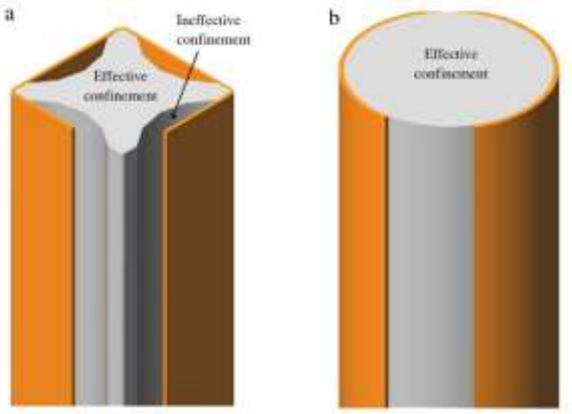

Fig. 2 Confinement effect in Square and circular column

Square and Rectangular Sections: Square and rectangular CFSTs are more common in practical construction because of their compatibility with beam–column connections in moment-resisting frames [1,3,17]. Patel and Thakkar [3] reported that such sections offer effective stiffness and drift control in tall buildings. However, the confinement efficiency is reduced compared to circular sections due to stress concentration at the corners and outward buckling of flat steel plates [10,13]. Liu [17] and Liu et al. [18] confirmed that while high-strength rectangular CFSTs exhibit significant load capacity, they are more prone to brittle concrete crushing and reduced ductility. Thus, these sections strike a balance between constructional convenience and structural performance.

Polygonal Sections (Hexagonal and Octagonal): Recent investigations have explored polygonal geometries as a compromise between circular and square forms. Ayough et al. [20] and Almamoori et al. [21] showed that hexagonal and octagonal CFSTs exhibit intermediate behavior in terms of confinement and axial strength. Their ductility and ultimate capacity were closer to circular sections, suggesting that polygonal CFSTs may provide both architectural flexibility and structural efficiency.

Special-Shaped Sections: Innovative section geometries such as triangular, fan-shaped, and semi-circular CFSTs have been studied for specific architectural requirements. Ren et al. [12] observed that while these shapes exhibit reduced axial capacity compared to circular CFSTs, they still outperform hollow steel tubes in terms of ductility and energy absorption. Such geometries may not be optimal for maximizing axial load resistance but are valuable for special design conditions where aesthetics and structural demands must be balanced.

III. EFFECT OF CONCRETE GRADE

The grade of infill concrete plays a decisive role in defining the load-bearing performance, ductility, and overall failure mode of Concrete-Filled Steel Tube (CFST) columns. Since the steel tube provides external confinement, the interaction between the steel and concrete core is highly dependent on the concrete strength. Research works [5,9–11,13,15,17–19,22] have consistently highlighted that the efficiency of confinement decreases as concrete strength increases, leading to different behavioral characteristics in Normal Strength Concrete (NSC), High Strength Concrete (HSC), and Ultra-High Strength Concrete (UHSC) infills.

Normal Strength Concrete (NSC, <60 MPa): NSC benefits most from the confinement provided by the steel tube. Studies by Hossain and Chu [11] demonstrate that circular CFSTs with NSC exhibit excellent ductility and strong post-peak load capacity due to delayed crushing of the concrete core. Ellobody et al. [9] and Sakino et al. [10] further confirmed that NSC-filled circular columns achieve a favorable balance between axial strength and deformation capacity, making them reliable for seismic applications.

High Strength Concrete (HSC, 60–100 MPa): The use of HSC improves the ultimate axial load capacity of CFSTs but reduces ductility. Liu [17] and Liu et al. [18] reported that HSC-filled rectangular columns displayed higher peak loads, yet their failure was characterized by earlier brittle crushing. Ibañez et al. [13] also observed that confinement efficiency decreases in square and rectangular CFSTs with HSC, as the steel tube is less effective in restraining high-strength concrete. Despite this, the increased load capacity makes HSC-filled CFSTs advantageous in tall buildings where strength demand governs design.

Ultra-High Strength Concrete (UHSC, >120 MPa): The application of UHSC in CFSTs has been investigated by Nguyen et al. [15] and Zhang & Guo [19]. Their results indicate significantly enhanced axial capacity; however, ductility is severely compromised. Thin-walled UHSC-filled CFSTs exhibited brittle failure modes, where the concrete core fractured abruptly without significant post-peak deformation. Such behavior highlights the importance of sufficient tube thickness and steel ratio to stabilize the brittle nature of UHSC under confinement [22].

VI. EFFECT OF STEEL GRADE & TUBE THICKNESS:

The properties of the steel tube—its yield strength and wall thickness—play a decisive role in governing the performance of Concrete-Filled Steel Tube (CFST) columns. These parameters directly influence confinement efficiency, resistance to local buckling, ductility, and overall axial load capacity.

Steel Grade: The use of higher-grade steels significantly improves the strength-to-weight ratio of CFST columns. Experimental studies [10,15,16] have demonstrated that steel grades with yield strengths up to 800 MPa can be effectively used in CFSTs, enabling smaller cross-sectional dimensions while achieving higher axial capacities. This makes high-strength steel particularly advantageous in tall buildings, where minimizing column size is critical to maximizing usable floor area. However, researchers caution that very high-strength steels may exhibit premature local buckling when combined with thin tube walls [15,16]. This reduces confinement effectiveness and can lead to brittle post-peak behavior if not counterbalanced by adequate wall thickness or sufficient steel ratio. Sakino et al. [10] confirmed that increasing steel grade improves initial stiffness and load resistance, but post-yield ductility is highly sensitive to wall slenderness.

Tube Thickness: The thickness of the steel tube governs confinement efficiency by restraining lateral expansion of the concrete core. Studies [4,9,22] show that thick-walled tubes (low diameter-to-thickness, D/t, or breadth-to-thickness, B/t, ratios) provide strong confinement, delay local buckling, and significantly enhance both strength and ductility. Ellobody et al. [9] found that thick-walled circular CFSTs could maintain high residual strength even after peak loading due to sustained confinement. Conversely, thin-walled tubes (high D/t or B/t ratios) provide limited confinement, leading to earlier local buckling and brittle failure modes [7,16]. Yang and Han [7] further highlighted that thin tubes under partial compression tend to buckle outward, reducing confinement uniformity and axial strength. A comprehensive study by Ibáñez et al. [22] emphasized that tube thickness has a more pronounced influence on post-peak ductility than steel grade alone, particularly for high-strength concrete infills. Their findings revealed that increasing wall thickness can compensate for the reduced ductility of high-strength concrete, thus achieving a balanced structural response.

Combined Influence: The combined role of steel grade and tube thickness suggests that optimal CFST design requires careful proportioning. While high-strength steels enable smaller and lighter sections, sufficient wall thickness is essential to prevent instability. Thin-walled, high-grade tubes tend to fail in brittle modes, whereas thicker tubes provide reliable confinement regardless of steel grade. Therefore, practical applications in tall buildings often prefer moderate-to-high steel grades paired with adequately thick tubes to achieve the desired balance of strength, ductility, and economy [9,15,22].

V. IMPLEMENTATION IN BUILDING STRUCTURES

The practical application of CFST columns in building structures has demonstrated significant advantages in terms of seismic performance, cost efficiency, drift control, and structural resilience. Their use in tall buildings is becoming increasingly prevalent, especially in regions with high seismic demand, due to their combined strength, stiffness, and ductility.

Seismic Performance: CFST systems exhibit superior behavior compared to conventional reinforced concrete (RCC) and pure steel structures under seismic loading. Comparative studies show that CFST buildings have shorter natural periods, reduced displacements, and improved energy dissipation [1–3]. Square CFST columns are often favored in moment-resisting frames because they simplify beam–column joint detailing and enhance drift control [1,3]. In contrast, circular CFSTs, owing to their uniform confinement, deliver higher ductility and improved performance during severe seismic excitations, including near-fault earthquakes [2]. Such characteristics make CFSTs highly suitable for tall structures in seismic zones.

Cost Efficiency: Economic evaluations highlight that CFST-based buildings can reduce construction costs by up to 39% compared to steel frame systems, largely due to optimized use of steel and reduced material consumption [1]. Additionally, the reduced member sizes in CFST frames allow for more usable floor space, further enhancing project efficiency.

Displacement and Drift Control: CFSTs improve lateral stiffness, resulting in lower storey displacements and inter-storey drifts compared to RCC and steel systems [1,2,3]. This structural advantage enables taller buildings to remain serviceable under both wind and seismic loading. Square CFSTs, in particular, demonstrate enhanced stiffness, contributing to effective drift control in high-rise applications [3].

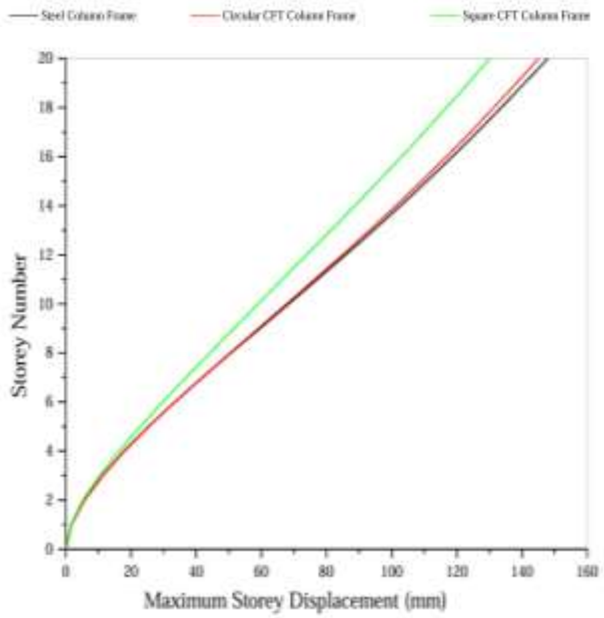

Fig.3 Comparison of maximum displacement

Structural Applications: Experimental and analytical studies further validate the implementation of CFSTs in tall buildings. Slender CFSTs can safely sustain axial compression provided the steel ratio is adequate, highlighting their suitability for vertical load-carrying systems in high-rise construction [16,19]. Impact performance assessments also reveal that CFSTs absorb substantial energy through plastic deformation, making them resilient against accidental loads such as vehicular impact and blast effects [8].

VI. RESEARCH GAP AND FUTURE SCOPE:

Despite the advantages of CFSTs, certain research and practice gaps remain:

Lack of dedicated design codes: Most countries, including India, rely on Eurocode 4, AISC, or AIJ for CFST design. These may not accurately predict behavior for high-strength materials or non-circular sections.

System-level seismic performance not fully explored: Majority of studies focus on isolated members. Limited research exists on CFST frame buildings using advanced analyses like nonlinear pushover and dynamic time-history.

Partial replacement in hybrid systems: Very few studies analyze the effect of partial replacement of steel columns with CFST in high-rise buildings, though it has potential for material optimization and seismic improvement.

Special and irregular geometries: Research on triangular, fan-shaped, and polygonal CFSTs is limited to stub column tests. Their behavior in irregular, unsymmetrical, or real-life building layouts is largely unaddressed.

Integration with dampers and bracings: Little work has been carried out on CFST frame buildings combined with energy-dissipation devices (dampers, bracings) under seismic loading.

Influence of material variations in tall buildings: Insufficient studies on the combined effect of different concrete grades (M30, M40), tube thickness variation, and steel yield strength on the overall performance of high-rise CFST structures.

High-strength and slender CFST members: More research is needed to optimize the use of UHSC and very high-strength steels in slender CFST columns, which face issues of brittle failure and local buckling.

Dynamic and impact loading: High-strength CFST members under impact, blast, and other dynamic loads are under-investigated, despite promising energy absorption capacity.

Long-term effects: Limited research exists on creep, shrinkage, and temperature effects in CFSTs, particularly for tall building applications.

VII. CONCLUSION

The analysis has shown that CFST columns **sections** provide the most effective confinement and ductility, whereas **square and rectangular geometries** are highly practical for moment-resisting frames due to simplified beam-column connectivity and enhanced drift control. While the integration of **Normal Strength Concrete (NSC)** maximizes ductile post-peak behavior, the use of **High and Ultra-High Strength Concretes (HSC/UHSC)** significantly increases load-bearing capacity, albeit with a trade-off in ductility that requires careful management through increased steel tube thickness.

Furthermore, the use of high-grade steel and optimized diameter-to-thickness ratios effectively mitigates local buckling, ensuring structural stability under extreme loads. Beyond mechanical performance, CFST systems provide significant economic advantages, with material cost reductions of up to **39%** and improved usable floor space. Ultimately, while CFST columns offer a robust alternative to conventional reinforced concrete and steel systems, future widespread implementation depends on the development of dedicated design codes and a deeper understanding of long-term effects and system-level dynamic responses.

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