Journal of Studies in Civil Engineering

EngiScience Publisher

Research Article

Flexural Strength and Ductility of a Concrete Filled Steel Tube Beam with Different Layouts

Kamaran Shekha Abdullah [1], Abbas H. Mohammed [2], Ilyani akmar Abu Bakar [3], Shwaz Hashim Noori [1,*], Meer Mariwan Omar [1]

[1] Department of Civil Engineering, Faculty of Engineering, Tishk International University, Sulaimani, 46001, Iraq

[2] Department of Civil Engineering, College of Engineering, University of Diyala, Diyala, 32001, Iraq

[3] School of Civil Engineering, College of Engineering, Universiti Teknologi MARA, Shah Alam, 40450, Malaysia

*Corresponding Author: Shwaz Hashim Noori, E-mail: shwazhashm@gmail.com

Article Info

Article History
Received May 09,2024
Revised Jun 08, 2024
Accepted Jun 10, 2024

Keywords

Beam strengthening
Composite beams
Concrete-filled steel tubes
Flexural strength
Steel Plate thickness

Abstract

Concrete-filled steel tube (CFST) is a composite member consisting of a steel tube filled with concrete, resulting in an enhanced structural element used in various types of construction. This research investigates the flexural strength of CFST members with varying steel tube thicknesses of 1.5 mm and 2.0 mm and different shapes: square, rectangular, and circular. The study aims to determine the flexural strength of each shape. Fifteen beams with different cross-sections and plate thicknesses were tested experimentally in the lab. The results indicated that 2.0 mm thick CFSTs, regardless of shape, exhibited superior strength and deformation resistance compared to thinner and hollow beams. This underscores the significance of using thicker plates and concrete to enhance structural integrity and durability. Notably, rectangular CFSTs demonstrated a 91.84% increase in strength, while circular beams showed greater deflection resistance, highlighting the importance of careful material selection and design choices in structural engineering to optimize performance and resilience under stress.

1. Introduction

Concrete-filled steel tubes (CFSTs) are composite structural elements made by encasing concrete within a steel tube. These components are primarily used in constructions that experience significant bending moments. Widely applied in various structural frameworks, CFSTs serve as beams, beam-columns in both braced and unbraced frames, and as columns, demonstrating their extensive utility in modern architecture [1].

Construction employs various beam types, such as reinforced concrete, shear, flexural, bending, prestressed, and composite beams. They are categorized by support types (simply supported, continuous, cantilever, fixed) and by shape (rectangular, circular, square, T-shaped, I-shaped, triangular). Engineers today have access to a broad selection of beams to efficiently tackle any construction project, particularly in the building sector. Nonetheless, the Concrete-Filled Steel Tube (CFST) system stands out as a modern and increasingly popular solution, capturing global interest due to its innovative features [2].

Research from the 1970s demonstrated that CFSTs and H-shaped beams are more ductile and have more strength than traditional reinforced concrete or steel systems. Infrastructures such as high-rise buildings, road and railway bridges, transmission towers, and offshore structures now utilize this technology. Japan, in particular, has been a leader in adopting CFST technology in its construction projects. Naka Kato, a Japanese pioneer, wrote the first technical paper on the use of circular CFSTs in power transmission towers [3].The Hollow Steel Tube (HST) forms the core of Concrete-Filled Steel Tubes (CFST) members, which are composite structures. Local buckling can occur in the flange of an HST when the width-to-thickness ratio (B/t) exceeds a certain threshold, potentially compromising the beam's plastic bending moment. To counteract this and enhance the performance of HST beams, filling them with concrete is an effective strategy. Although this addition slightly increases the overall weight, it is a reliable method to boost the strength, ductility, and stiffness of HST members [4].

To date, the bulk of research on Concrete-Filled Steel Tubes (CFST) has centered around rec-tangular, circular, and square sections, which are common cross-sectional shapes in construction [5]. A recent study amassed a substantial database of 3103 tests [6], focusing on rectangular and circular CFST columns subjected to axial compression and combined axial force with bending moments. These test results were subsequently compared against predictions from various design codes to evaluate their suitability for designing high-strength materials.

Several studies have explored the performance of elliptical Concrete-Filled Steel Tube (CFST) members, including stub columns and beam-column behavior. Polygonal cross-sections, commonly used in telecommunication structures, have garnered interest among researchers for use in composite constructions like hexagonal and octagonal shapes. While there is limited research on the flexural be-havior of circular CFST components, rectangular and square shapes have received more attention. En-hancing the understanding of the flexural behavior of rectangular and square CFST members is crucial to promoting the utilization of circular steel tubes in CFST structures. Therefore, the primary aim of this research is to experimentally investigate the flexural behavior of CFST beams with square, rectan-gular, and circular cross-sections under flexural loading.

In this study, fifteen Concrete-Filled Steel Tube (CFST) beams were examined, divided into three shapes: rectangular, square, and circular, with four specimens for each shape. Half of the steel used in the test had a thickness of 2.0 mm, while the other half had a thickness of 1.5 mm. Half of the specimens were filled with concrete, using a mix ratio of 1:2:4 for each shape and size, and were sub-jected to flexural loading. The remaining steel specimens, of various sizes for rectangular, square, and circular shapes, were tested without concrete under flexural loading as well.

The objective of these tests was to compare the flexural resistance of Concrete-Filled Steel Tube (CFST) beams with different cross-sectional shapes, namely rectangular, square, and circular. The in-ves-tigation involved varying the thicknesses of the steel tubes, using 2mm and 1.5mm, to determine the effect on flexural strength. Additionally, we included a standard concrete beam without any steel rein-forcement as a control specimen. This comparative analysis aimed to identify which shape and thick-ness of CFST beams offer the greatest resistance to flexural stress. CFST beams face challenges, partic-ularly during curing, as there is no space between the steel tube and the concrete. This may necessitate prefabrication or the use of specialized materials for curing. The research extensively investigates CFSTs both experimen-tally and theoretically, aiming to showcase their capability, ductility, and strength under flexural loading, as well as understand their behaviors.

2. Experimental Program

2.1 Specimens

Table 1 summarizes the details of the 15 specimens. Three different types of steel tubes are used, such as rectangular, circle, and square, as shown in Figure. 1. For each type, five specimens were investi-gated, which include the base, which is the beam without hollow steel and concrete fill (CB), and act such as a benchmark for other cases. The next specimens are the hollow steel beam without concrete fill (HSB) for the plate thicknesses of 1.5 mm and 2.0 mm, tested separately. The final specimens are the concrete-filled steel beams (CFS) for both plates, 1.5 mm and 2.0 mm, tested separately.

The test parameters for rectangular and square steel tubes included the tube width (*d*) of 100 mm and 50 mm, respectively. All the specimens had a height (*H*) of 100 mm and a length (*L*) of 1,000 mm, with a diameter (*D*) of 100 mm, for circular shape. There are two different type of tube thickness (*t*) used for all specimen:1.5 mm and 2.0 mm, and the yield stress of steel *Fy* (236 and 246 MPa).

The specimens are labeled, and to make it easier for the reader, for all shapes there are common symbols such as (CB) representing the control beam, (HSB) representing the hollow steel beam, and (CFS) representing the concrete filled steel beam. Also, to show the comparison between different shapes, the labels *S*, *R,* and *C* represent the square, rectangular, and circle shapes, respectively.

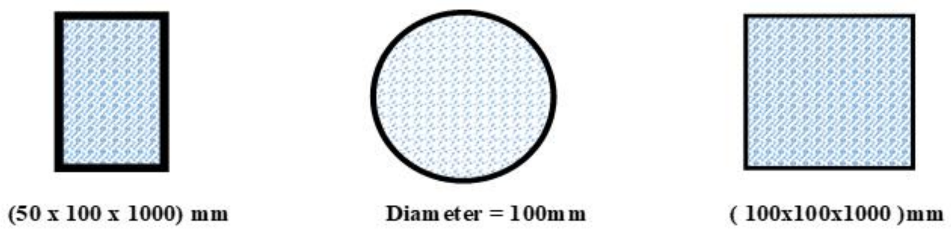


Figure 1. CFST beam shapes and dimensions

Table 1. Detail of specimen

Shapes	Specimen ID	d (mm)	H (mm)	(t) mm	d/t ratio	Length (L) (mm)	Steel strength (F_y) (MPa)
Rectangular	CBR	50	100	---	---	1000	---
	HSBR-1.5	50	100	2.0	25	1000	236-246
	HSBR-2.0	50	100	1.5	33.33	1000	236-246
	CFRT 1.5	50	100	2.0	25	1000	236-246
	CFRT-2.0	50	100	1.5	33.33	1000	236-246
Square	CBS	100	100	---	---	1000	---
	HSBS-1.5	100	100	1.5	66.667	1000	236-246
	HSBS-2.0	100	100	2.0	50	1000	236-246
	CFST 1.5	100	100	1.5	66.667	1000	236-246
	CFST-2.0	100	100	2.0	50	1000	236-246
Circle	CBC	D100		---	---	1000	---
	HSBC-1.5	D100		1.5	66.667	1000	236-246
	HSBC-2.5	D100		2.0	50	1000	236-246
	CFCT-1.5	D100		1.5	66.667	1000	236-246
	CFCT-2.0	D100		2.0	50	1000	236-246

Note: d= width, H= height, D= diameter, t= plate thickness, L= Length, and f_y= yield stress of steel.

2.2. Mix Proportion

Choosing the right mix proportion is vital for improving the durability, strength, and workability of concrete. A well-balanced mix ensures that the concrete can withstand environmental conditions, support heavy loads, and be easily handled during construction. By carefully selecting the materials and their proportions, builders can ensure that the concrete meets the specific requirements of the project. This means choosing a good mix proportion that is most conservative for the concrete, so in this investigation (1:2:4) proportion is used for all cases of concrete filled steel tube beams, and it is one of the good mixtures that come from standard, is strong, and has more usage in fields [7-8]. Table 2 finds each component of (cement, sand, gravel, and water) that is used for 1 m^3 of concrete for mix proportion.

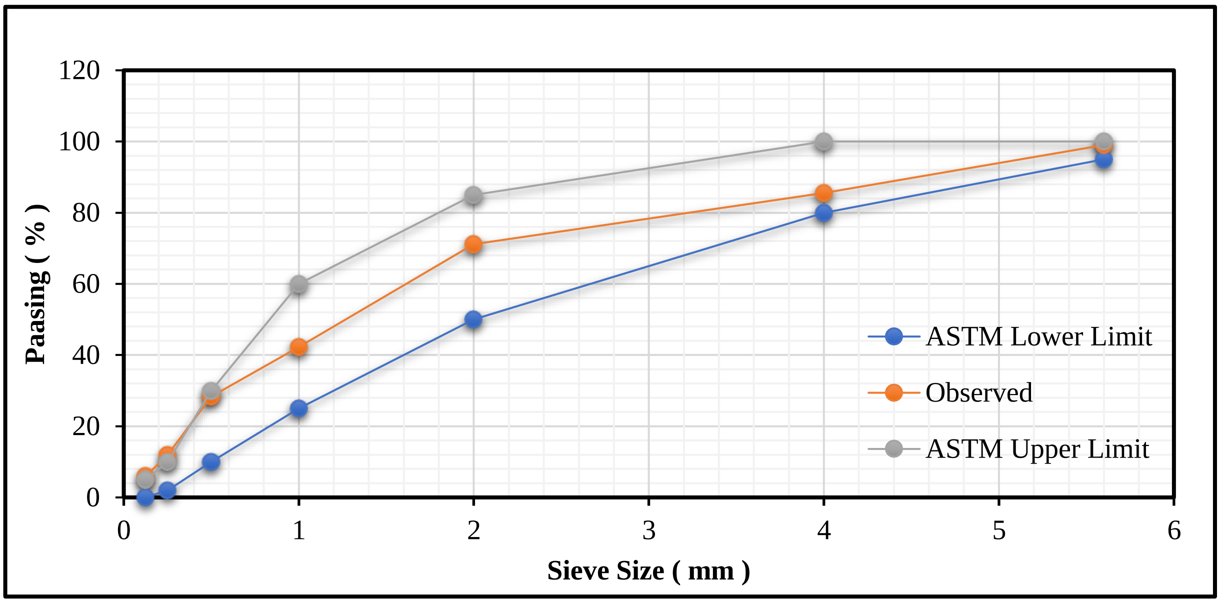
Table 2. Mix Proportion of Self Compact Concrete (SCC)

Concrete Filled Steel Tube Beam Type	Volume (m^3)	Water (m^3)	Cement (m^3)	Sand (m^3)	Gravel (m^3)
All case	1	0.087	0.213	0.426	0.853

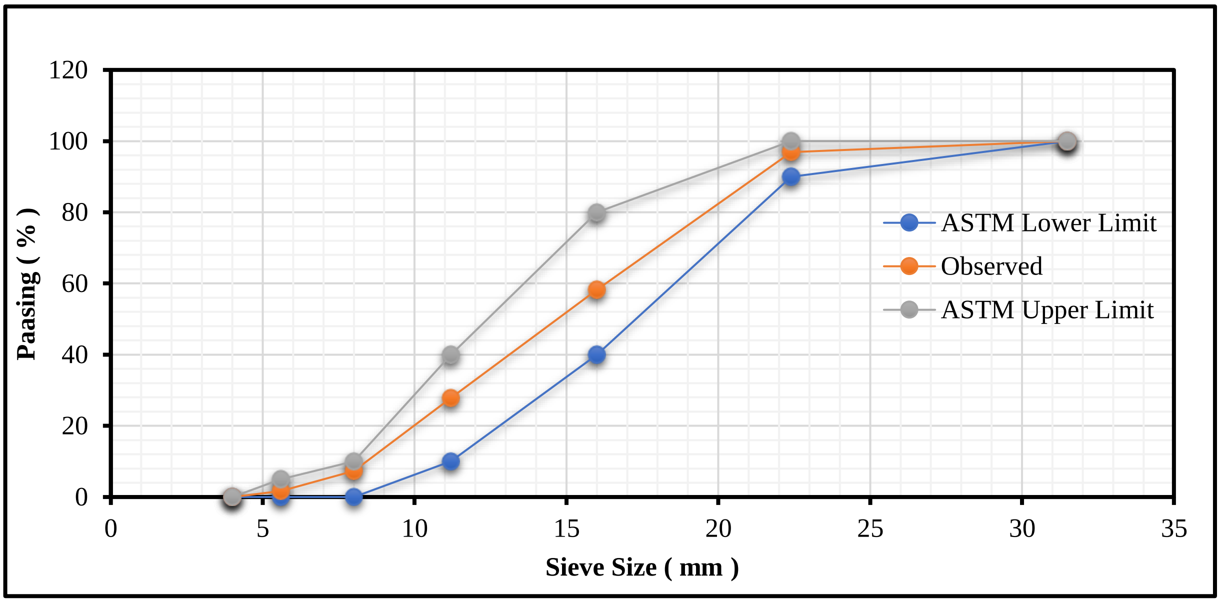
2.3. Test Setup, Instrumentation, and Loading Procedure

2.3.1. Material Characterization

In this investigation, five preliminary tests were conducted to determine the flexural strength of concrete-filled steel tubes. Initially, the Sieve Analysis Test assessed aggregate particle size gradation by shaking a 1005 g sample for fine and a 610 g for coarse aggregate used through progressively smaller sieves, crucial for evaluating the impact on concrete's workability and strength [9]. The results were compared for ASTM in lower and higher limits, as shown in Figure. 2.



a) Fine aggregate



b) Coarse aggregate

Figure 2. Sieve Analysis; a) fine aggregate and b) coarse aggregate

Following this, the Concrete Slump Test involved filling a lubricated mold with concrete in four layers, each tamped 25 times, to measure workability by the slump after leveling and cleaning [10]. Subsequently, the Normal Consistency Test for cement determined the necessary water percentage for the cement paste, using up to five molds due to failures, to achieve a Victa plunger penetration of 10 mm [11]. Additionally, the Setting Time Test monitored the time taken for cement to become non-workable, marking initial and final setting times by the needle's penetration limit, and the below equation was used, where t is equal to the time of the initial setting [12];

$$(90 + 1.2 * t)\ t \tag{1}$$

The Compressive Strength Test then evaluated the load-bearing capacity of concrete cubes, requiring precise placement in a testing machine and careful loading to record the maximum weight and failure type [13]. Finally, the Flexural Strength Test compared normal concrete to concrete-filled steel tubes using a three-point load test on specimens that were mixed, cast, and cured for 28 days before testing under controlled conditions to ascertain performance through systematic force application and dimension measurement at critical points as shown in Figure. 3 [14].

Figure 3. Flexural Strength Test

2.3.2. CFST Beam Test Setup, Instrumentation and Loading Procedure

In setting up the tests for CFST beams with rectangular, square, and circular shapes, meticulous attention was paid to ensuring consistency and accuracy throughout the experimental process. The test setup involved securing each beam specimen onto a sturdy testing rig equipped with load cells and displacement sensors to precisely measure load and deflection. Prior to testing, the instrumentation was carefully calibrated to ensure reliable data collection. The loading procedure followed a standardized protocol, with each CFST beam subjected to incremental point loads applied at designated locations along its length. The loading regimen was designed to simulate realistic structural conditions and induce flexural stress evenly across the beams. Load increments were carefully controlled, allowing sufficient time for stabilization and data recording at each stage. Throughout the testing process, continuous monitoring of load and displacement parameters was conducted to capture the behavior of the CFST beams accurately. Any deviations or anomalies were promptly addressed to maintain the integrity of the test results. Additionally, safety precautions were implemented to prevent any structural failures that could compromise the experimental setup or endanger personnel. Overall, the test setup, instrumentation, and loading procedure were meticulously executed to ensure reliable and meaningful data acquisition, providing valuable insights into the flexural behavior of CFST beams with different shapes.

3. Results and Discussion

After waiting for 28 days, all beams were prepared and subjected to point load testing until they could no longer sustain additional loads. Initially, the performance of control beams was evaluated against beams with hollow steel tubes across all groups. It was observed that filling the tubes with concrete significantly enhanced the beams' moment-carrying capacity and decreased their deflection, indicating that the Concrete-Filled Steel Tubes (CFSTs) offered a stiffer response under load up until failure. Using the results of these tests, the next section will discuss the implications of these findings on structural design and application [15,16].

3.1. Initial and Final Setting

After selecting a 10 mm penetration depth for the samples and using a water/cement (w/c) ratio of 0.26, tests were conducted to determine when the concrete begins to harden, known as the initial setting time, as illustrated in Figure. 4. Initially, no change was observed up to 120 minutes, but at 125 minutes, there was a noticeable difference in penetration depth. By 150 minutes, the penetration was 22 mm. Standard practices allow us to define the initial setting time at 25 mm penetration. However, direct measurement showed 26 mm at 145 minutes and 22 mm at 150 minutes. Therefore, we used interpolation to calculate the exact moment when penetration reached 25 mm, which was at 146.25 minutes. This calculated time fits well within the standard requirements, and using this value, we determined that the final setting time was 265.5 minutes, which aligns with the expected standards. The standard for initial setting time between 30 minutes and 2 hours and Final Setting Time Typically ranges from 4 to 8 hours [12].

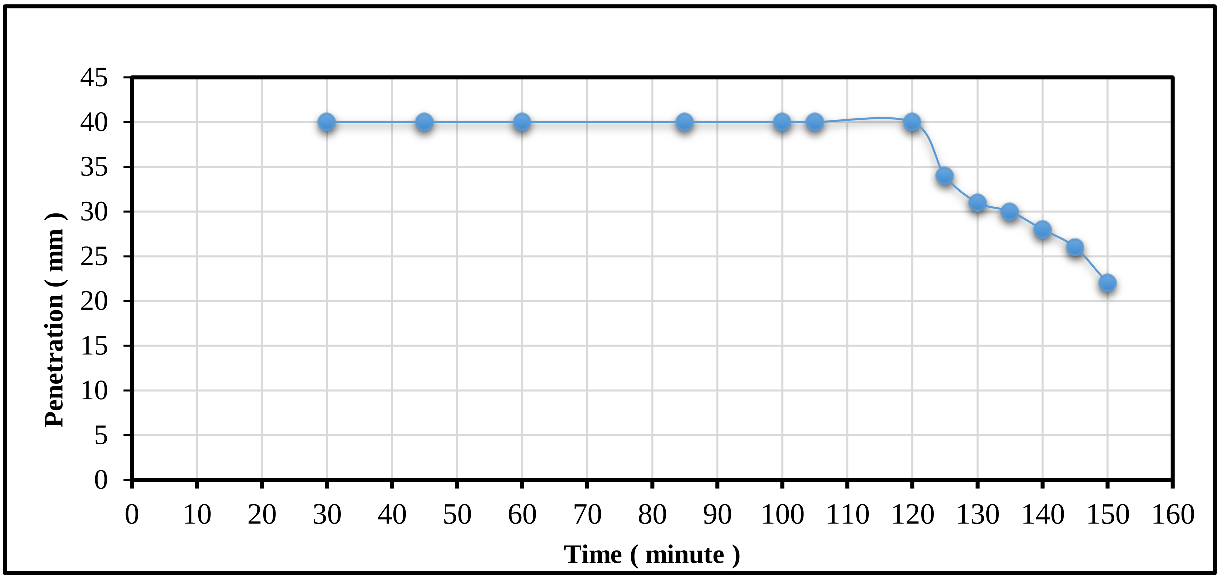


Figure 4. Setting Time Test

3.2. Consistency Test

In order to ensure robust results for the consistency test, a total of five samples were initially prepared. Unfortunately, two of these samples did not meet the expected criteria and were therefore considered failures. These outcomes were meticulously documented and analyzed through graphical representations to enhance the interpretability of the data. According to established standards, a penetration depth of 10 mm was selected as a critical benchmark for this test. This specific depth corresponds to a water-to-cement (w/c) ratio of approximately 0.26, which is indicative of the mixture's consistency level under the test conditions [17]. This parameter is crucial as it helps in evaluating the workability and hydration characteristics of the cement paste, providing essential insights into its potential performance in practical applications, as shown in Figure. 5 [11].

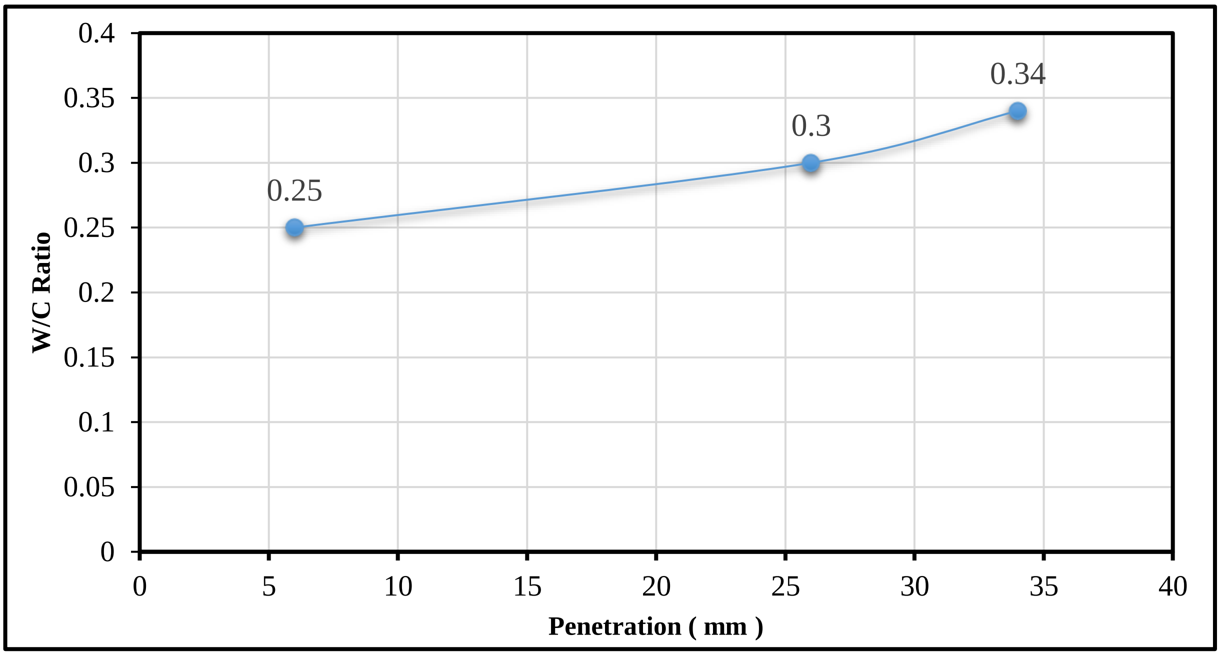


Figure 5. Consistency Test

3.3 Compressive Strength

To ensure academic rigor, the mean compressive strength of the tested samples was found to be approximately 15.976 MPa, as shown in Table 3. Although this value might appear slightly lower than expected, it is still advantageous for our purposes [18]. This is particularly evident when comparing the performance differences in the flexural strength tests between standard control concrete and concrete-filled steel tubes. Importantly, our primary concern was not solely the strength of the concrete because the same concrete mixture was used consistently across all samples and structural components, thus eliminating variability in the experimental setup. Additionally, the slump test, which measures the workability of the fresh concrete utilized in these tests, yielded a slump of about 5 cm—this result falls well within the acceptable range for our research parameters.

Table 3. Compressive strength of cubic

Cubic compressive strength MPa	Average MPa
16.15	
17.61	
16.43	15.98
17.28	
14.11	
14.28	

3.4 Failure mode

In all cases, beams displayed deflection capacity, with CFST beams failing due to significant tensile rupture towards the end of testing, as shown in Figure. 6. For the first group, hollow steel tubes experienced inward local buckling and side buckling towards the conclusion of the test, but without any rupture. Additionally, the control beam showed outward local buckling, side buckling, and eventual rupture. Furthermore, another reinforced specimen exhibited outward local buckling of the steel plate in the compression zone, leading to rupture, but without involving the flanges [19, 20].

Figure 6. Group of steel tube failure mode, A) Hollow steel tube, B) CFST beams

3.5. Comparison of Failure Load Beams for Different Geometric Shapes

This study previously examined beams of three different shapes: square, rectangular, and circular. It was found that the load-bearing capacities of these beams vary significantly depending on their geometric configurations, with no enhancements from plates and uniform plate thickness throughout.

3.5.1. Controlled Beam Without Plate

As depicted in Figure. 7, the comparison of the controlled beams between these three shapes showed that the square beams had the highest load tolerance, managing to support approximately 5.78 kN. This was followed by rectangular beams at 3.44 kN, with circular beams trailing behind at about 2.73 kN.

The results indicated that square beams are capable of bearing 40.48% and 53.1% more load than rectangular and circular beams, respectively. The relatively lower strength of the circular beams can be attributed to the nature of load distribution; the load being applied at a single point tends to concentrate the force centrally, reducing overall structural resistance.

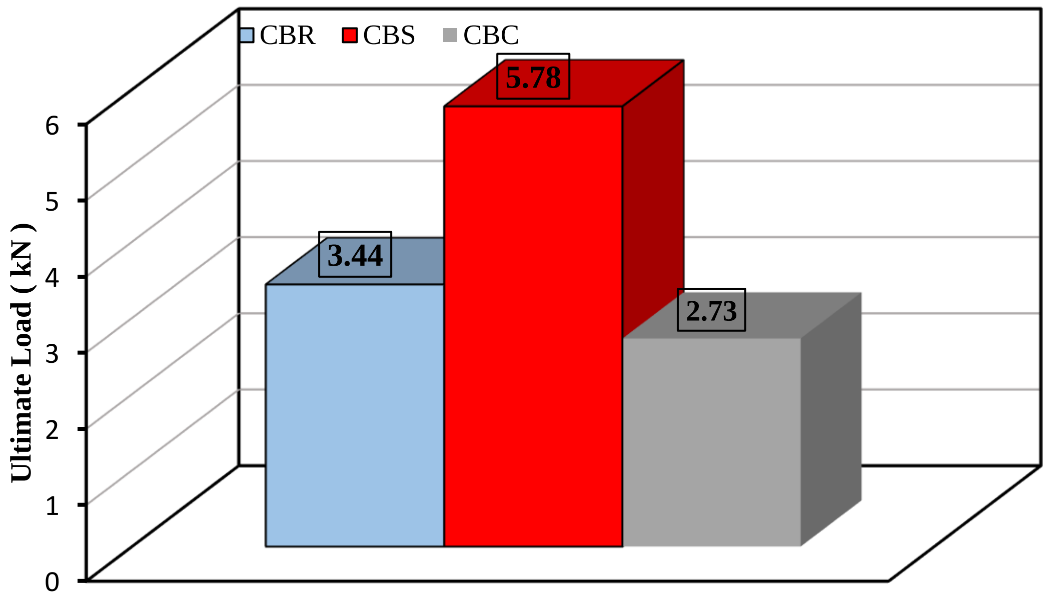


Figure 7. Plane Concrete Beam Capacity

3.5.2 Hollow Steel Tube Beam

The study depicted in Figure. 8 compared the ultimate load capacities of hollow steel beams with differing plate thicknesses of 1.5 mm and 2.0 mm, across three geometric shapes: square, rectangular, and circular.

At a thickness of 1.5 mm, square beams demonstrated the highest strength, reaching 20.78 kN, followed by circular beams at 17.34 kN, and rectangular beams at 11.51 kN. Significantly, square beams surpassed their circular and rectangular counterparts by 16.6% and 44.6%, respectively. Circular beams, on the other hand, exhibited 33.6% greater strength compared to rectangular beams. For the 2.0 mm thickness, square beams again exhibited superior strength at 29.68 kN, followed by rectangular beams at 26.41 kN, and circular beams at 21.62 kN. Square beams were stronger by 11% and 27.2% compared to rectangular and circular shapes, respectively. Rectangular beams showed 18.14% higher strength compared to circular ones [21].

Overall, the findings revealed that beams with a 2.0 mm plate thickness consistently outperformed those with 1.5 mm in terms of strength resistance. Specifically, the strength resistance increased by 56.4% for rectangular, 30% for square, and 19.8% for circular shapes when comparing the two thicknesses. This indicates a significant enhancement in structural integrity with increased plate thickness across all tested geometries [22].

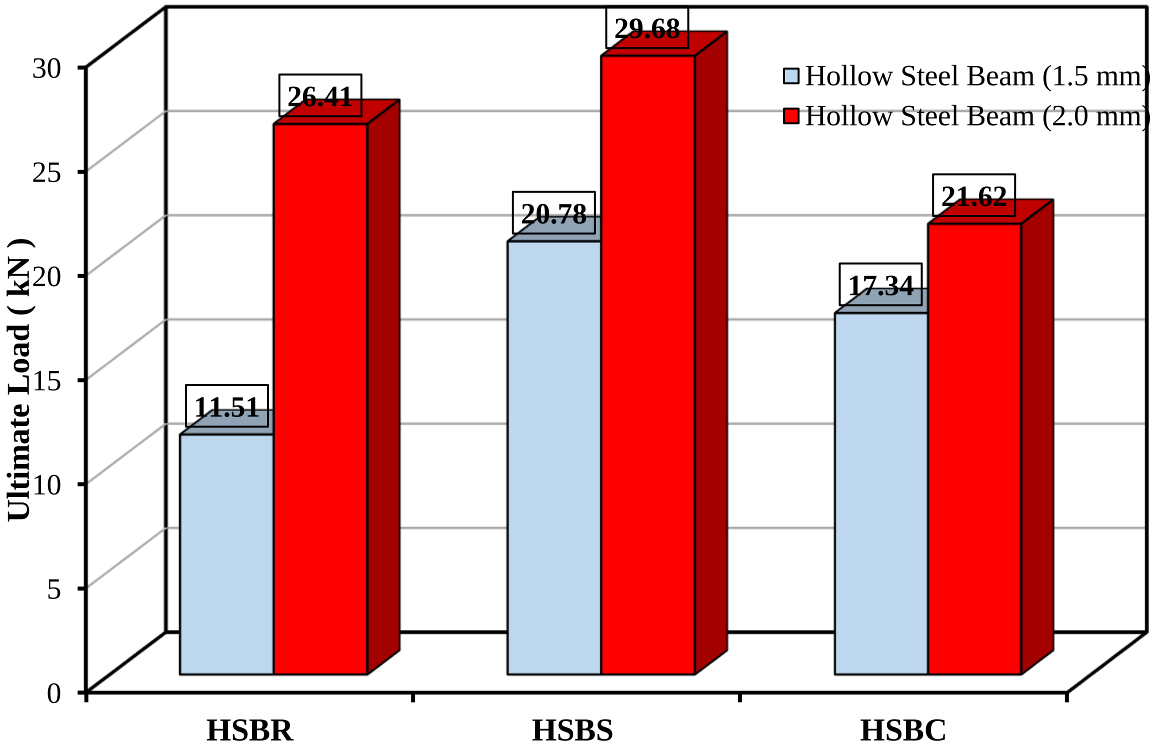


Figure 8. The comparison of ultimate load for hollow steel beam for 1.5 mm and 2.0 mm for geometric shape square, rectangular and circular.

3.5.3. Concrete Filled Steel Beam

Figure. 9 illustrates a comparative analysis of the ultimate load capacities of concrete-filled steel beams with plate thicknesses of 1.5 mm and 2.0 mm, across square, rectangular, and circular geometric shapes. For the 1.5 mm plate thickness, the ultimate load capacity was highest for CFCT at approximately 55.65 kN, followed by CFST at 41.28 kN, and CFRT at 27.76 kN. The circular beams showed notably higher strength resistance, exceeding that of the square and rectangular beams by 25.8% and 32.8%, respectively. In contrast, with a 2.0 mm plate thickness, circular beams once again topped the chart with an ultimate load of about 72.91 kN, with square and rectangular beams capable of handling loads up to 60.48 kN and 42.16 kN, respectively. This configuration showed that circular beams outperformed the others, having 17% and 30.3% more strength resistance than square and rectangular beams, respectively [23].

Overall, the data indicates that beams with a 2.0 mm thickness demonstrate significantly greater strength resistance across all shapes compared to those with 1.5 mm plates. Moreover, irrespective of the plate thickness, the strength hierarchy consistently favored the circular, followed by square, and then rectangular shapes. This pattern highlights the enhanced durability provided by concrete when used in conjunction with hollow steel structures, particularly noting a substantial increase in load-bearing capacity for circular beams, nearly tripling their strength with both tested thicknesses.

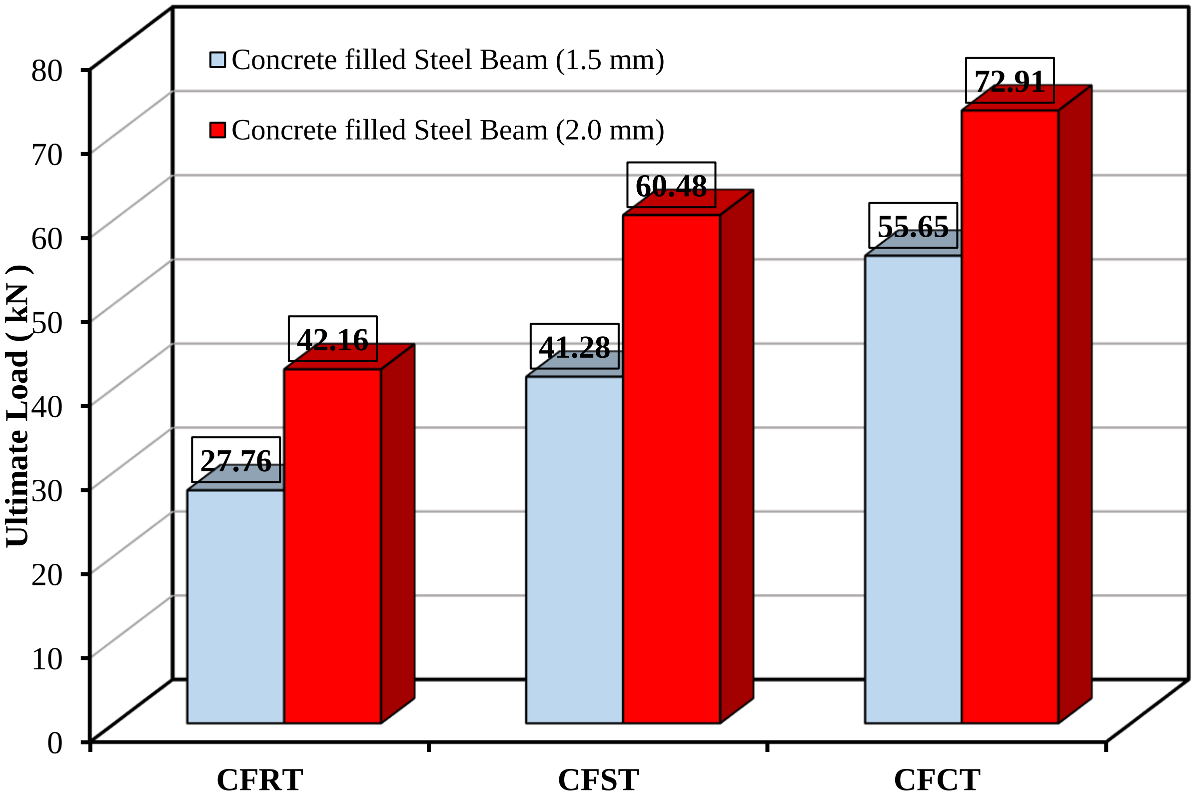


Figure 9. The comparison of ultimate load for concrete filled steel beam for 1.5 mm and 2.0 mm for geometric shape rectangular, square, and circular.

In summary, the evaluation of hollow and concrete-filled steel beams with steel plate thicknesses of 1.5 mm and 2.0 mm reveals that concrete-filled steel beams with a 2.0 mm thickness exhibit the highest strength resistance. They are followed in descending order by concrete-filled steel beams with a 1.5 mm thickness, and then by hollow steel beams with thicknesses of 2.0 mm and 1.5 mm, respectively, as shown in Figure. 10. This pattern clearly suggests that both an increase in steel plate thickness and the addition of concrete within the steel significantly enhance the beam's ability to withstand forces.

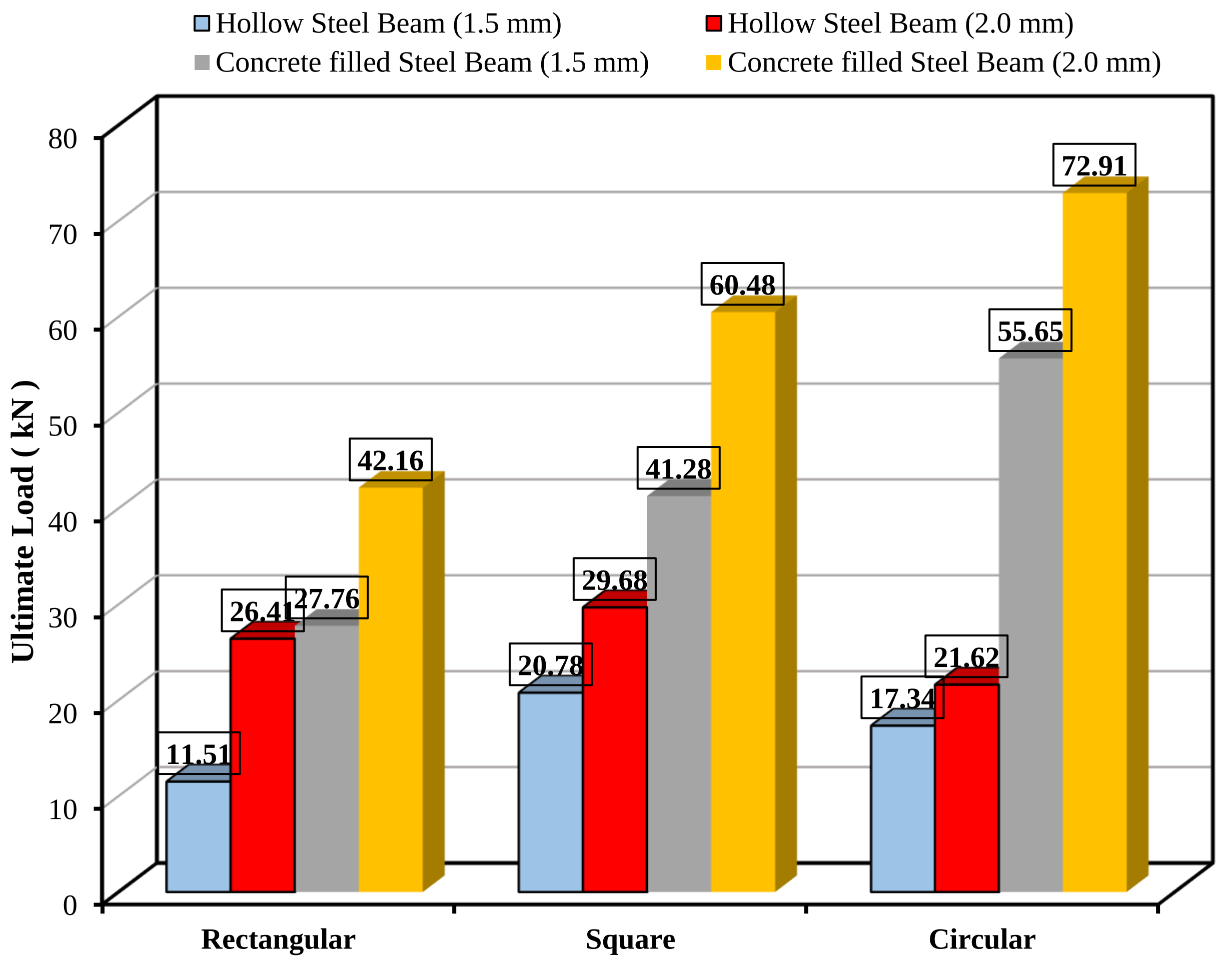


Figure 10. The comparison of ultimate load for hollow steel beam and concrete filled steel beam for 1.5 mm and 2.0 mm for geometric shape rectangular, square, and circular.

3.6. Comparison of Failure Load of Same Beams for Plate Thickness 1.5 mm and 2.0 mm

This study examined the strength resistance of hollow steel beams and concrete-filled steel beams compared to control beams without steel plates, which maintained the same geometric shape throughout. The findings reveal significant differences in strength among the various beam types, underscoring the crucial role of plate thickness in improving structural integrity. The research emphasizes the importance of choosing the right plate thickness to enhance durability and performance in engineering applications.

3.6.1. Rectangular Geomatic Shape

Figure. 11 illustrates the effects of plate thickness on flexural strength by comparing a range of specimens to a controlled beam with a rectangular shape. This detailed comparison reveals that Concrete-Filled Steel Tubes (CFRT) with a 2.0 mm thick plate exhibit the highest resistance, followed sequentially by

CFRT with a 1.5 mm plate, Hollow Steel Box Sections (HSBR) with a 2.0 mm plate, HSBR with a 1.5 mm plate, and finally the Controlled Beam (CBR). When these findings are quantified, it becomes apparent that, compared to the controlled beam, the CFRT (2.0 mm) shows an increase in resistance of 91.84%, the CFRT (1.5 mm) by 87.6%, the HSBR (2.0 mm) by 87%, and the HSBR (1.5 mm) by 70%, underscoring the significant impact of increasing plate thickness on enhancing the structural integrity of the beams [24, 25].

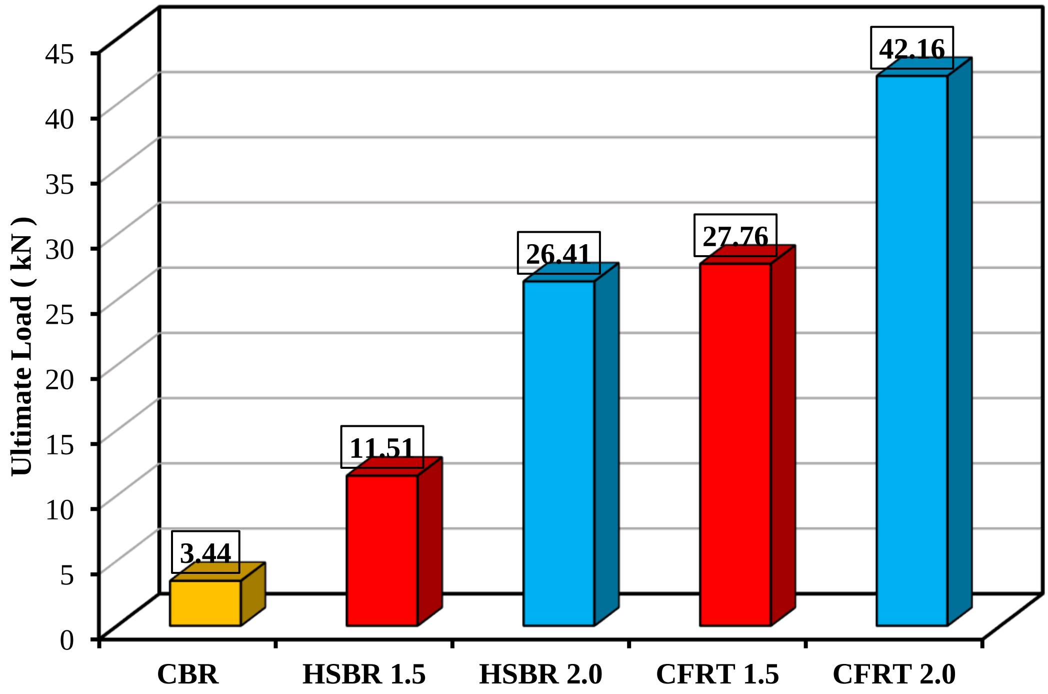


Figure 11. The effects of plate thickness on flexural strength by comparing a range of specimens to a controlled beam with a rectangular shape.

3.6.2. Square Geomatic Shape

Figure. 12 delves into how variations in thickness affect flexural strength by comparing a range of beam specimens against a benchmark control beam with a square shape. Similar patterns were observed in tests with rectangular-shaped beams, though with differing values. Strength resistance was observed in descending order: CFST with 2.0 mm thickness, CFST with 1.5 mm, HSBS with 2.0 mm, HSBS with 1.5 mm, and finally, the Controlled Beam (CBS). In-depth analysis indicated substantial increases in resistance relative to the control beam: CFST (2.0 mm) showed a 90.44% increase, CFST (1.5 mm) by 86%, HSBS (2.0 mm) by 80.5%, and HSBS (1.5 mm) by 72.2%, highlighting how thickness significantly boosts structural strength [26].

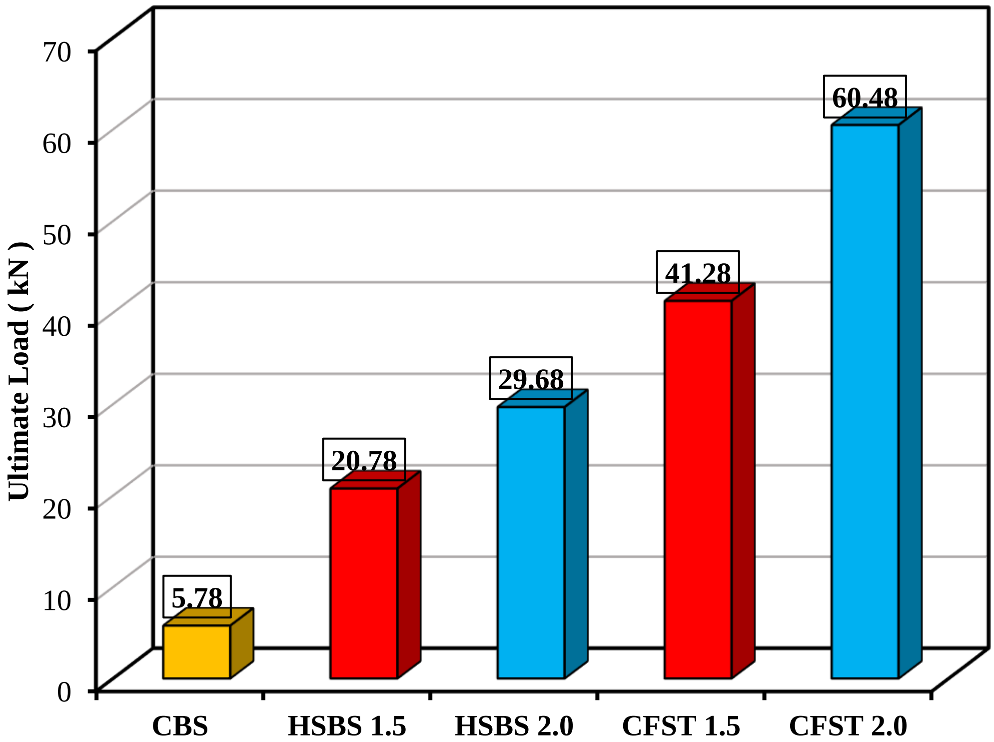


Figure 12. The effects of plate thickness on flexural strength by comparing a range of specimens to a controlled beam with a square shape.

3.6.3 Circular Geomatic Shape

Figure. 13 offers an in-depth look at how flexural strength varies across different beam types with varying plate thicknesses, compared against a control beam shaped like a circle. The study shows that beams made from Concrete-Filled Steel Tubes (CFCT) are consistently more resistant to bending than both hollow steel beams and the standard control beams. This superior performance is noted across all tested thicknesses, indicating that filling steel tubes with concrete markedly improves their ability to withstand bending forces [27].

In detail, the data indicate that CFCT beams significantly surpass the control beam in terms of flexural strength for each tested thickness. The extent of increased strength resistance is remarkable, with all specimens demonstrating enhancements over the control by multipliers of 26.7, 20.38, 7.92, and 6.35, respectively. This extensive analysis highlights the exceptional strength of concrete-filled steel structures when facing flexural stress and points out the vital influence of both material choice and structural thickness in engineering design.

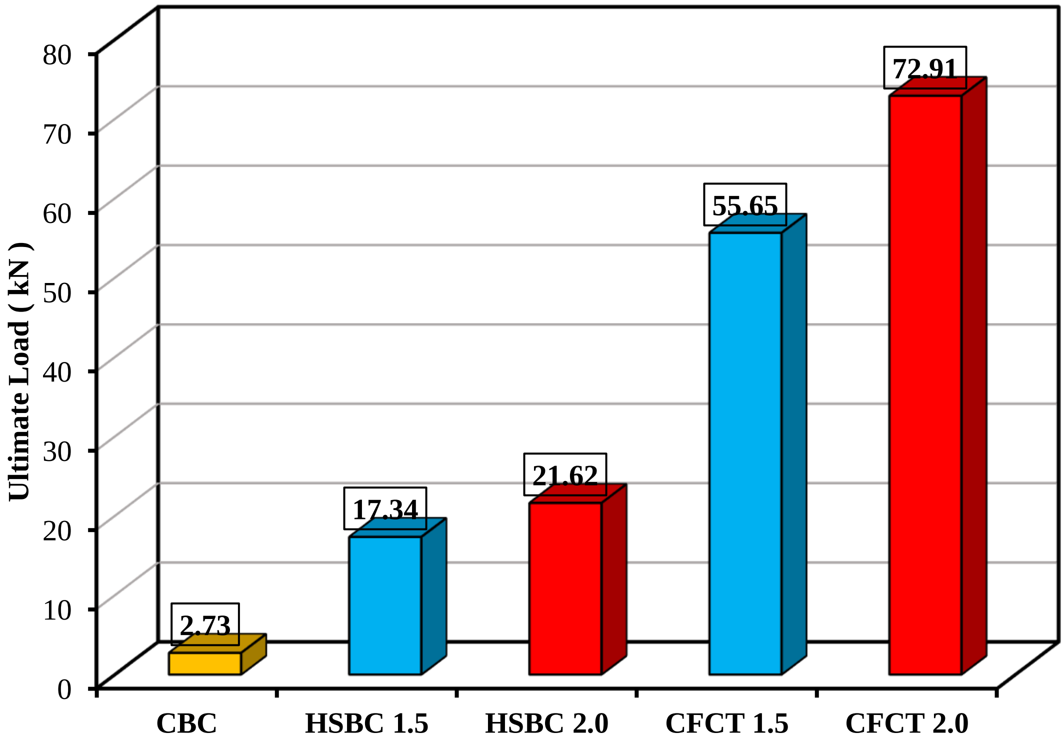


Figure 13. The effects of plate thickness on flexural strength by comparing a range of specimens to a controlled beam with a circular shape.

In conclusion, the analyses of rectangular, square, and circular beams underscore the critical role of plate thickness and material composition in enhancing flexural strength, as demonstrated across multiple sections above. Concrete-Filled Steel Tubes (CFST) with a 2.0 mm thickness consistently showed superior resistance in all geometric shapes, markedly outperforming Hollow Steel Box Sections (HSB) and Controlled Beams (CB). For example, CFST in rectangular beams increased strength by 91.84%, and similar trends were noted in other shapes. This pattern reveals that thicker plates and the incorporation of concrete significantly boost structural integrity and resilience. These findings highlight the importance of careful material and design choices in engineering to improve the durability and performance of structural elements under stress.

3.7. Ultimate Load and Maximum Deflection

Table 4 in our report offers an exhaustive overview of the data gathered during this study, which includes deflection metrics across various beam configurations. Notably, circular beams tend to deflect more than other beam types. This phenomenon is primarily due to the moment of inertia that greatly affects the beam's capability to withstand bending and twisting, impacting its deflection properties significantly. In the case of beams constructed from plain concrete, the deflection recorded was extremely low—virtually undetectable—hence, these figures were entered as zero in our dataset as they were too minor for precise measurement. Additionally, the findings reveal that circular concrete-filled steel tubes (CFSTs) show superior resistance to bending and distortion over beams made of plain concrete and those of other shapes, highlighting their durability and efficiency in structural uses. This comprehensive evaluation aids in deciphering the performance of different material compositions and beam shapes under pressure, offering vital information for refining structural designs to enhance their stability and durability [28].

Table 4. Collection of all samples that tested with deflections.

Shapes	Specimen ID	Ultimate Load (kN)	Max. Deflection (mm)
Rectangular	CBR	3.44	---
	HSBR-1.5	11.51	15
	HSBR-2.0	26.41	10
	CFRT-1.5	27.76	3
	CFRT-2.0	42.16	6
Square	CBS	5.78	---
	HSBS-1.5	20.78	35
	HSBS-2.0	29.68	30
	CFST-1.5	41.28	3
	CFST-2.0	60.48	4
Circle	CBC	2.73	---
	HSBC-1.5	17.34	42
	HSBC-2.0	21.62	40
	CFCT-1.5	55.65	28
	CFCT-2.0	72.91	62

4. Conclusion

This research investigated concrete-filled steel tubes and compared this composite shape with normal control concrete and hollow steel tubes. In this study, 15 specimens were tested, and three different shapes of steel tubes were utilized: rectangular, circular, and square. Each shape category included five types of specimens: the base model without any steel or concrete (CB) serving as a benchmark, hollow steel beams (HSB) without concrete fill tested at both 1.5 mm and 2.0 mm thicknesses, and concrete-filled steel beams (CFST) also tested at these two thickness levels separately. In conclusion, the study of hollow and concrete-filled steel beams with 1.5 mm and 2.0 mm thicknesses shows that the 2.0 mm concrete-filled beams exhibit the highest strength resistance, followed by 1.5 mm concrete-filled and hollow beams. This trend confirms that greater thickness and concrete integration substantially enhance beam durability and force resistance. The analysis across square, rectangular, and circular beams highlights the essential roles of plate thick- ness and material composition in boosting flexural strength. Concrete-Filled Steel Tubes (CFSTs) with a 2.0 mm thickness consistently outperformed Hollow Steel Box Sections (HSB) and Controlled Beams (CB) in all shapes; for instance, CFRT-2.0 rectangular beams showed a strength increase of 59.60% compared with HSBR-2.0. This pattern demonstrates that thicker plates and concrete significantly en- hance structural integrity and resilience, underscoring the need for thoughtful material and design deci- sions in engineering to optimize the durability and performance of structures under stress. Circular beams exhibit greater deflection than others, primarily because of the moment of inertia, which greatly affects their resistance to bending and twisting. Additionally, the study highlights that circular concrete-filled steel tubes (CFSTs) are more resistant to deformation than other beam types, emphasizing their superior structural strength and efficacy. The use of circular concrete-filled steel tubes (CFSTs) in construction is well-established, as exemplified by their previous application in a bridge project in China [29], as mentioned earlier. This underscores the viability and effectiveness of CFSTs as a robust construction material. Additionally, rectangular, and square CFSTs also provide significant strength and are favored in various construction projects due to their geometric advantages, which make them easy to implement.

Funding: The authors declare that this research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of Competing Interest The authors declare that they have no known competing of interest.

References

[1] Chen, J., & Chan, T. M. 2019. Experimental assessment of the flexural behaviour of concrete-filled steel tubular beams with octagonal sections. *Engineering Structures*, 199, 109604.

[2] Zhan, Y., Zhao, R., Ma, Z. J., Xu, T., & Song, R. 2016. Behavior of prestressed concrete-filled steel tube (CFST) beam. *Engineering Structures*, 122, 144-155.

[3] Morino, S., & Tsuda, K. 2003. Design and construction of concrete-filled steel tube column system in Japan. *Earthquake Engineering and Engineering Seismology*, 4(1), 51-73.

[4] Schneider, S. P., & Alostaz, Y. M. 1998. Experimental behavior of connections to concrete-filled steel tubes. *Journal of Constructional Steel Research*, 45(3), 321-352.

[5] Thai, S., Thai, H. T., Uy, B., & Ngo, T. 2019. Concrete-filled steel tubular columns: Test database, design and calibration. *Journal of Constructional Steel Research*, 157, 161-181.

[6] Xiong, M. X., Xiong, D. X., & Liew, J. R. 2017. Flexural performance of concrete filled tubes with high tensile steel and ultra-high strength concrete. *Journal of constructional steel research*, *132*, 191-202.

[7] Su, N., Hsu, K. C., & Chai, H. W. 2001. A simple mix design method for self-compacting concrete. *Cement and Concrete research,* 31(12), 1799-1807.

[8] Shafaatian, S. M., Akhavan, A., Maraghechi, H., & Rajabipour, F. 2013. How does fly ash mitigate alkali–silica reaction (ASR) in accelerated mortar bar test (ASTM C1567)? *Cement and Concrete Composites,* 37, 143-153.

[9] ASTM. 2006. Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates, ASTM C136, Annual Book of American Society for Testing Materials Standards, Vol. C 04.02

[10] ASTM, Standard C143-00, "Standard Test Method for Slump of Hydraulic Cement Concrete," ASTM International, West Conshohocken, PA

[11] Smith, J., & Brown, L. 2023. The effects of low water-to-cement ratio on the mechanical properties and durability of high-performance concrete. *Journal of Advanced Concrete Technology*, *21*(3), 145-156.

[12] ASTM standard C187, "Standard Test Method for Determination of Normal Consistency of Cement with" Vicat's Apparatus.

[13] ASTM standard C191, Standard Test Method for Determination of Initial Setting Time of Cement with Vicat's Apparatus.

[14] ASTM 2001. ASTM C39: Standard test method for compressive strength of cylindrical concrete specimens. ASTM International, West Conshohocken, PA, USA.

[15] Zhao, X., Han, L., & Lu, H. 2019. Experimental study on the behavior of concrete-filled steel tubes (CFSTs) under axial and flexural loads. *Journal of Constructional Steel Research*, *158*, 45-58.

[16] Guo, T., & Ma, J. 2019. Experimental study on flexural behavior of concrete-filled steel tube beams with different cross-sectional shapes. *Journal of Constructional Steel Research*, 156, 99-111.

[17] ASTM C 78, 2002. Standard test method for flexural strength of concrete (using simple beam with third-point loading), American Society for Testing and Materials, West Conshohocken.

[18] Smith, J., & Brown, L. 2022. Influence of recycled aggregate on compressive strength of concrete. *Journal of Sustainable Construction Materials and Technologies*, *15*(4), 225-233.

[19] Gardner, L., Saari, N., & Allwinkle, M. E. N. 2010. Flexural behavior of circular concrete-filled steel tube (CFST) beams with external steel rings. *Journal of Structural Engineering*, 136(4), 425-433.

[20] Taljsten, B. 2003. Behavior of reinforced concrete beams with external FRP plates. *Journal of Composites for Construction*, 7(1), 58-64.

[21] Gkantou, M. 2017. *Response and design of high strength steel structures employing square and rectangular hollow sections* (Doctoral dissertation, University of Birmingham).

[22] Wang, J., Afshan, S., Gkantou, M., Theofanous, M., Baniotopoulos, C., & Gardner, L. 2016. Flexural behaviour of hot-finished high strength steel square and rectangular hollow sections. *Journal of Constructional Steel Research*, 121, 97-109.

[23] Patel, V. I. 2020. Analysis of uniaxially loaded short round-ended concrete-filled steel tubular beam-columns. *Engineering Structures,* 205, 110098.

[24] Du, Y., Chen, Z., Liew, J. R., & Xiong, M. X. 2017. Rectangular concrete-filled steel tubular beam-columns using high-strength steel: Experiments and design. *Journal of constructional steel research*, 131, 1-18.

[25] Gho, W. M., & Liu, D. 2004. Flexural behaviour of high-strength rectangular concrete-filled steel hollow sections. *Journal of Constructional Steel Research*, 60(11), 1681-1696.

[26] Guo, L., Zhang, S., Kim, W. J., & Ranzi, G. 2007. Behavior of square hollow steel tubes and steel tubes filled with concrete. *Thin-Walled Structures*, 45(12), 961-973.

[27] Elchalakani, M., Zhao, X. L., & Grzebieta, R. H. 2001. Concrete-filled circular steel tubes subjected to pure bending. *Journal of constructional steel research*, 57(11), 1141-1168.

[28] Lin, Y., Jiang, L., & Li, G. 2020. Experimental study on flexural behavior of CFST beams with ultra-thin steel tubes. *Journal of Structural Engineering*, 146(6), 04020058.

[29] Li, Q., Zhang, H., & Wang, Y. 2021. An overview of concrete and CFST arch bridges in China. *Journal of Bridge Engineering*, 26(5), 04021007.