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Strengthening of Concrete-Filled Double Skinned Circular Steel Tubular (CFDSCT) Column: A Review Study

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ABSTRACT

Due to its beneficial characteristics, such as its high load carrying capacity, good seismic resistance, fire resistance, high ductility, and quick construction, a concrete filled double skinned steel circular tubular (CFDSCT) column is a structural member that is frequently used in high-rise buildings. Many studies have proved that the factors controlling the bearing capacity of this type of column are column diameter-to-tube thickness (*D/t*), column length-to-diameter (*L/D*), central void ratio (χ), the yield of steel tubes (f_y), and concrete strength (f_c). In this study, the enhancement of the load-bearing capacity of the CFDST column was highlighted by adding some external details and changes to its structure. These external details and changes gave the structure more confinement and improved contact zoon between concrete and tubes. The differences between the previous test results were significant; a good additional improvement in compressive strength and bond strength reached 51% and 225%, respectively, higher than the conventional CFDSCT. This improvement was achieved by some changes in the outer tube structure or by using external details on the outer and inner tubes. This review also showed how the load-bearing capacity of the CFDSCT column could be improved if the best results from the above factors were added to the CFDSCT results.

1. INTRODUCTION

Two concentric outer and inner circular steel tube profiles with concrete filled in between them make up a concrete filled double skinned steel circular tubular (CFDSCT) member. similar to the composite column, which combines the benefits of filled concrete with steel tubes. However, the development of high-rise structures, long spans, and heavy load structures necessitates the employment of columns with larger cross-sections, causing the frame structures too heavy and the foundations bearing an excessive quantity of load, which is not ideal for seismic resistant design. As a solution to this issue, CFDST were proposed [1-7]. Therefore, the CFDST column has been extensively studied and used in buildings. The cross-sectional area of CFDST members can be significantly reduced while the structural performance is outstanding [8-10]. The CFDST column exhibits outstanding mechanical benefits, such as larger load-carrying capacities, higher bending, shearing stiffness, better fireproof properties, and more collapse preventing abilities [11]. In addition, architects may allocate a portion of the column centre to passing services such as electrical wiring and downpipes in multistorey buildings [12, 13]. It is done to achieve some of the aesthetic reasons, facilitate the work, and shorten implementation time. so that it is practical to utilise CFDST columns in tall structures. The inner steel tube, which holds the filled concrete within, is in addition to the outside steel tube. It is not the intention of pouring the core concrete to reduce the weight and improve the cyclic performance of CFDST columns [14]. Additionally, according to previous studies, such composite stub columns have an axial load-carrying capacity that is 10% to 30% greater than the sum of their individual component strengths [15-18]. In comparison to the equivalent composite concrete filled steel tubular (CFST) member, the CFDST member reduced the construction self-weight by a ratio of 8.30%, which could lower the implementation's cost [19]. To increase the carrying capacity of the CFDST column, numerous studies were conducted. Researchers examined how the inner and outer tube thickness, concrete strength, steel tube yield, the ratio of the central void, and length-to-diameter affected the CFDST column strength in those investigations. The findings showed that these factors had a substantial impact on the carrying capacity of this type of composite column. For both compression and bending of the CFDST column, the ductility and energy dissipation increase when the parameter D/t of the outer tube rises from 16.7 to 25 [20]. Additionally, by lowering the value D/t for both the inner and outer steel tubes of the CFDST column, good energy dissipation and ductility were attained [21]. Circular CFDST columns are more ductile and have better energy dissipation than square ones [22]. At the compression face of the CFDST column, the steel tube swells outward as it reaches its yielding strain [23]. Numerous researchers evaluated a total of 11 CFDST stub columns under axial loads [24]. Results showed that the strength-to-weight ratio was developed outstandingly by exchanging the core concrete in the CFST column with a hollow steel (inner) tube [24]. The PVC-U inner pipe's increased skin thickness (more than 3mm) has little to no effect on the concrete confinement activity. The CFDSCT column's final axial load can be somewhat increased as a result. The CFDSCT column's ultimate axial stress rises linearly with sandwich concrete but falls as the hollow section ratio rises [25]. According to a different study, CFDST columns exhibit increased ductility and strength under axial loading. The outcomes demonstrated the significant effects of changes in concrete's compressive strength, steel sections' yield stress, and CFDST columns' diameter and thickness [26].

Other researchers have noted that reducing the inner tube's diameter and increasing the volume of concrete improved the CFDST column's carrying capacity [27]. Additionally, the carrying capacity of the CFDST column is increased by shortening it and enlarging it [28]. The effect of sandwich concrete on the axial bearing capacity of such composite columns was the subject of a study. This study came to the conclusion that a considerable improvement in the column's bearing capacity was caused by a rise in concrete strength [29]. The outer and inner tube shapes have an impact on the stability and bending stiffness of the CFDST column as well. When both tubes are circular, the performance is often greater because of the increased local stability. Contrarily, building beam-to-column connections for square CFDSTs is easier and they often have higher bending stiffness [30-38].

However, a number of studies focused on the notion that the confinement generated by the external steel tube is what provides CFDST columns significant strength. By enhancing the method of the outer tube's confinement and using a Fiber Reinforced Polymer (FRP) jacket around the outer tube, the CFDST column's bearing capacity was improved [39]. Additionally, steel bar rings were employed as an external confinement to the outer tube of the CFDST column to improve its strength, stiffness, and ductility [40-42]. Carbon Fiber Reinforced Polymer (CFRP) strips with a width of 50 mm and a space between them of 20 mm were used by Prabhu et al. [43] as an external confinement to increase the strength of CFST. Another study in this field evaluated the effectiveness of steel shear studs welded into the inner face of the external tube of a CFDST column to strengthen the bond between the concrete and steel tube. The findings showed that the bolted shear studs prevented shear failure and significantly increased the ductility of the specimens. The strength of the local buckling in the outer tube was reduced and the confinement effect was enhanced by reducing the bolted shear stud spacing. The addition of the bolted shear studs also significantly improved the confinement effect that the outer tube provided [44].

Based on the above survey, the improvement in the load-bearing capacity of the CFDST was achieved by some changes in the outer tube structure or by using external details on the outer and inner tubes. Therefore, in this review, the enhancement of the load-bearing capacity of the CFDST column was highlighted by adding some external details and changes to its structure.

2. LITERATURE REVIEW

A CFDST column is a construction member that includes two circular layers of steel with a sandwich layer of concrete between them. This type of column gives good load carrying capacity when compared with reinforced concrete columns due to the confinement of outer and inner steel tubes in concrete. Utilizing steel tubes with high yield strengths and concrete with high strengths but reduced flexibility increased the performance of this composite column [45]. For these kinds of buildings, it is believed that the interface between concrete and steel tubes is the key to strength. Therefore, researchers studied how to enhance these regions to obtain enhanced strength. The addition of externally strengthened details to each or both inner and outer steel tubes improve the CFDSCT column's strength and ductility. Many different details were added to the tubes of the CFDSCT column by many researchers in terms of enhancement of the confinement and interface zoon between concrete and steel tubes.

Dong and Ho [46] tested five CFDST columns with the same sections and material properties. One of these specimens is considered a reference. The other four specimens were supplied by external steel rings with different spacing (5to, 10to, 15to, and 20to). Figure 1 shows the reference CFDST column and the CFDST columns supported by external steel rings with different spacing. According to the findings shown in Table 1, it is possible to deduce that a reduction in the distance between the steel rings led to an increase in the axial load capacity. In addition, the bearing capacity of the strengthened specimens, which were provided by an external steel ring, was found to be superior to that of the reference specimen, which lacked the external ring. The improvement of the outer steel tube confinement to sandwich concrete was what allowed for this development to be realised.

(a) (b)

Figure 1. CFDST Columns: (a) Without External Steel Ring and (b) With External Steel Rings (s=5to, 10to, 15to and 20to) [46]

Table 1. Results of load carrying capacity of the CFDST with different external steel ring spacing

Specimen	Steel ring spacing (mm)	Load carrying capacity (kN)	Enhancement %
CFDST Ref.	0	2852	-
CFDST 5to	25	3464	21.4
CFDST 10to	50	3107	8.9
CFDST 15to	75	2971	4.1
CFDST 20to	100	#	-

Result is NOT included because of poor concrete compaction [46].

Ho and Dong [47] studied the effect of the hollow ratio of the CFDST column strengthened by external steel bars with different spacing on it carrying capacity. It was concluded that the increase in the hollow ratio of the CFDST column with external steel rings had a negative effect on load-carrying capacity. Hsiao et al. [48] concluded that the local buckling was delayed on the external steel tubes when using stiffener inner steel tubes. Energy dissipation was both alleviated and accelerated by the decline in column moment capacity. Additionally, stronger concrete reduces column ductility brought on by greater strain demands placed on the outer tubes, which led to earlier local buckling followed by rupture failure. Chen et al. [49] compared the axial load capacity for two types of CFDST columns, circular and dodecagonal, as shown in Figure 2. Each column with four lengths, 1,000mm, 2,000mm, 2,500mm, and 3,500mm, used the same steel tube diameters on the outer (Do) and inner (Di), with the same thickness of the tubes, were examined. The results showed increases in axial carrying capacity for dodecagonal CFDST columns beyond the length of 2,000mm by ratios of 13%, 7%, and 32.6% when compared with circular CFDST columns with different lengths of 2,000mm, 2,500mm, and 3,500mm, respectively, as shown in Table 2. Also the test results demonstrate that the specimens of the dodecagonal section column can offer sufficient ultimate strengths and deformation capacity. The improvement was due to the global buckling resistance of dodecagonal CFDST columns achieved by edges more than the circular CFDST column.

Table 2. Test result for CFDST columns

Specimen	Length (mm)	Axial load (Nu) (kN)
CFDST	1000	3423
CFDST	2000	3013
CFDST	2500	3256.5
CFDST	3500	2923
CFDST dodecagonal	1000	2990
CFDST dodecagonal	2000	3424.5
CFDST dodecagonal	2500	3490
CFDST dodecagonal	3500	3876.5

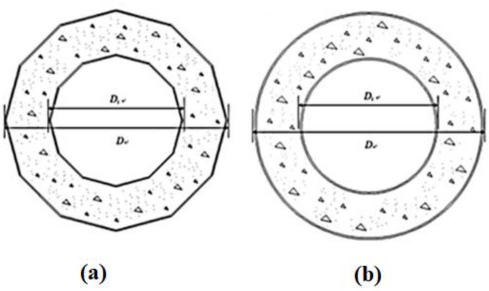

Figure 2. CFDST Sections (a) Dodecagonal; (b) Circular [49]

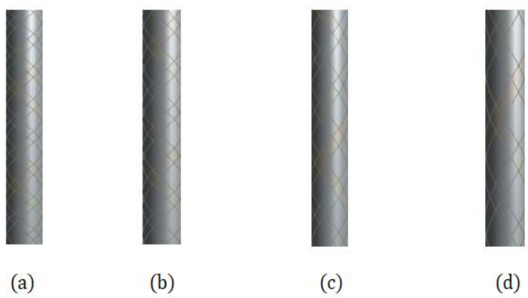

Figure 3. CFDST Columns Wrapped with FRP Strips by Angles: (a) 40°, (b) 45°, (c) 50°, (d) 60° [50]

Skaria and Kuriakose [50] conducted study on the load carrying capacity of CFDSCT columns that are subjected to axial loads and are ringed by Fiber Reinforced Polymer (FPR) strips. One of these CFDST column models was put to the test. There are five total models. Because the FRP wrapping had been removed from one of these models, it was used as a specimen to serve as a reference. Wrapping FRP in a cross-helically at 40 degrees, 45 degrees, 50 degrees, and 60 degrees respectively resulted in the creation of the other four models, which are depicted in Figure 3. After inspecting the specimens, we found that the angle of wrapping that resulted in the CFDST column having the highest load-carrying capability was 45 degrees.

The findings demonstrated that the CFDST column enclosed by FRP had a better load-carrying capability when it was angled away from the helically cross at a 45° angle. As demonstrated in Table 3, the increase in load carrying capacity over the reference specimen was 20.1%. The reason, based on the authors, is that angle 45° provides a suitable covered area of the column more than the greater angles and the wrapping process is more stable than that of smaller angles. This angle accomplishes the best confinement of the column. Therefore, the strengthening of the column's confinement process is what causes the percentages of the bearing capacity to increase.

Table 3. The enhancement of load carrying capacity of CFDST column wrapping by FRP with different angles

Specimen	Angle of wrapping	Carrying load capacity (kN)	Enhancement%
CFDST column without wrapping	-	1063	-
CFDST column wrapping	40°	1092	2.7
CFDST column wrapping	45°	1277	20.1
CFDST column wrapping	50°	1242	16.8
CFDST column wrapping	60°	1217	14.5

Hasan and Ekmekyapar [51] presented the results of an axial compression test on CFDST columns that had been strengthened by welded reinforced bars. As can be seen in Figure 4, the steel reinforcement bars were welded in variable quantities to either the internal surface of the outer tube or the exterior surface of the inner tubes, depending on which surface they were to be attached to. Results of the load-carrying capacity of CFDST showed the high efficiency of stiffened steel bars when welded with an inner tube. It was increased by increasing the number of steel bars as in specimen DS6. It was found that the enhanced carrying capacity was more than 18% compared with the reference specimen DS. All enhanced percentages of carrying capacity are shown in Table 4. In this regard, the researcher suggested a modified empirical formula based on a formula provided by Yu et al. [52]. This modified empirical formula was used to estimate the axial load capacity of such reinforced columns in term of inner tube thickness and outer tube thickness less than 3 mm (thin-thin). The suggested modified formula which resulted accurate values of axial load carrying capacity [51], as follow:

$$N_{u,Yu,mod} = (1 + 0.5\left(\frac{\xi}{1+\xi}\right)\Omega\left(f_{syo}A_{so} + f_{ck}A_c\right) + N_{i,u} + N_{sb} \quad (1)$$

where, $\xi = \left(\alpha.\frac{f_{sy}}{f_{ck}}\right)$, $\alpha = \left(\frac{A_s}{A_c}\right)$, Ω is a solid proportion, $\Omega = \frac{A_c}{(A_c+A_k)}$, $f_{ck} = \frac{f_c'}{1.5}$.

A_s is an outer steel tube area, A_C is a concrete cross section area, A_k is a hollow part area, $N_{u,Yu,mod}$, N_{iu} and N_{sb} are the cross-sectional strength of CFDST reinforced by steel bars, cross sectional strength of inner steel tube, and cross sectional strength of steel bars.

$$N_{i,u} = f_{syi}A_{si}$$

where, f_{syi} is yield stress of the inner tube, A_{si} is a cross sectional area of the inner tube.

$$N_{sb} = f_{sby}A_{sb}$$

where, f_{sby} is yield stress of the reinforcing bars, A_{sb} is an area of steel bars.

Additionally, the authors modified the AISC method formula (AISC, 2016) [53] which provided relatively conservative estimates of the stiffened CFDST columns for both thin-thin and thick-thick of outer and inner tubes, which were about 10% lower than those of the experiments. The proposed modified formula to predict the strength capacity of stiffened CFDST column [51], as follow:

$$N_{u,mod} = f_{syo}A_{so} + f_{syi}A_{si} + C_2 f'_c A_c + f_{sby}A_{sb} \quad (2)$$

where, C_2 is a factor takes 0.95 when the inner and outer tubes are circular, otherwise, it assumes 0.85.

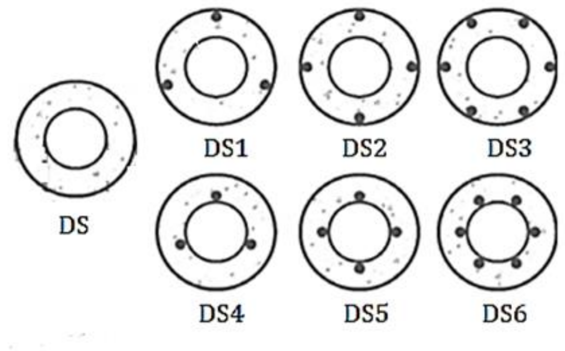

Figure 4. CFDSCT column specimens [51]

Table 4. The load carrying capacity of CFDSCT column with different steel bars welded

Specimen	Load carrying capacity (kN)	Enhancement %
DS	1622	-
DS1	1745	7.5
DS2	1789	10.3
DS3	1850	14
DS4	1812	11.7
DS5	1835	13.1
DS6	1916	18.1

Ekmekyapar and Al-Eliwi [54] suggested a new method to enhance the performance of the CFDST column. It was conducted by connecting the outer and inner tubes of the column with three redial steel bars with a diameter of 8 mm each, 200 mm of column length. They concluded that a good enhancement of the load-carrying capacity of the CFDST column with uniform failure was obtained. Huang et al. [55] developed the conventional CFDST column by using Fiber Reinforced Polymer (FRP) instead of an outer steel tube and the inner tube strengthened by steel stiffeners. Here we focused on three models (the study included a lot of specimens), which give an imagination about the specimen's configuration as shown in Figure 5. The first specimen was without stiffeners, the second with four steel stiffeners, and the third with six steel stiffeners. Each specimen was the same size, and it had the same qualities of the substance throughout. The stiffener that was used in the research was a steel zigzag plate that was welded to the exterior of the inner steel tube, as can be seen in Figure 6.

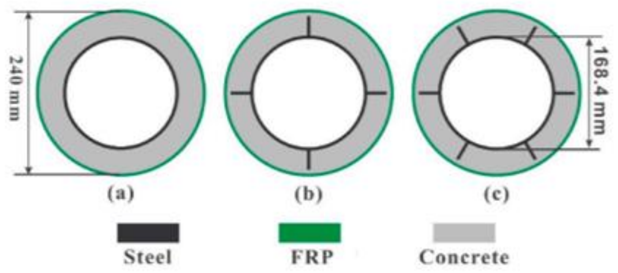

Figure 5. CFDST specimens with FRP (A) Without stiffeners (B) With four steel stiffeners (C) With sex steel stiffeners [55]

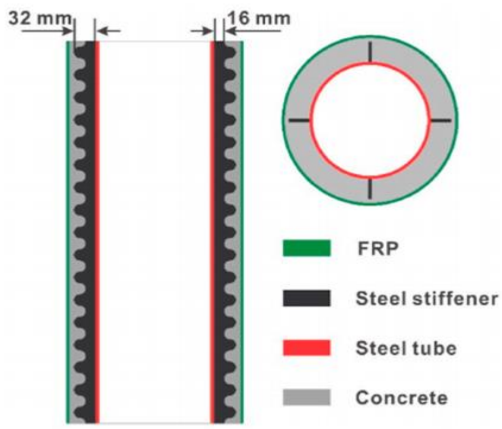

Figure 6. Details of steel stiffeners [55]

The results showed that the CFDST specimen with six stiffeners gained more axial load capacity by 51% than the specimen without stiffeners. Also, the specimen with four stiffeners had 29% axial load capacity more than the reference specimen. Table 5 shows the load-carrying capacity of CFDST specimens. This increasing was due to enhance in the composite action between the three components of the column specimen (FBR, concrete, and steel tubes). Also, the presence of stiffeners led to dispersion in the hoop stress to which the concrete was exposed. The two gains mentioned above have been enhanced as the number of tonics increases. Therefore, such enhanced composite action and reduction in hoop stress introduce additional/better confinement onto the concrete and thus leads to a higher axial load of the specimen.

Table 5. Enhancement of load-carrying capacity with steel stiffeners number

Specimen	No. of Stiffener	Load carrying capacity (kN)	Enhancement %
CFDST a	0	1715	-
CFDST b	4	2200	29
CFDST c	6	2598	51

Hasan and Ekmekyapar [56] presented three specimens of the CFDSCT column with different types of bonds. The bond was represented by using shear studs, steel bars, and steel rings welded on the outer face of the inner tubes. Each of these stiffeners was used alone to evaluate the improvement in the bond between concrete and steel tubes. The stiffer and conventional specimens are shown in Figure 7. The result showed that the specimen DS3 had a 225% increment, DS2 had a 200% increment, and DS1 had a 41% increment more than that of DS0, respectively, in terms of bond strength as pointed out in Table 6. It is believed that the main mechanism contributing to the bond strength in CFDST specimen was the wedging strength of the reinforcing bars against the concrete. An important consequence is that the inner steel tubes reach full compression capacity before allowing slip due to the enhanced bond strength of the internal rings, which greatly improves withstanding push-out loads. As a result of reinforcing bars or shear studs or steel rings embedded onto the inner steel tube, the friction force considerably increased with increased slip, causing a large increase in the post-ultimate stage. Additionally, only the interface friction force, which is proportionate to the push-out load, continues to produce shear force on CFDST specimens after the peak point. Recognizing that the bond-slip increases as the coefficient of friction decreases.

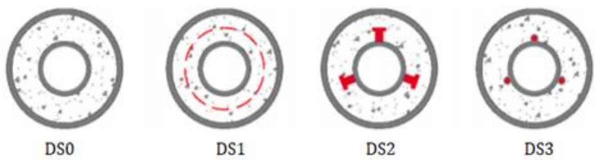

Figure 7. CFDST Specimens with Different Stiffeners [56]

Table 6. The enhancement of CFDST specimens with different stiffener type

Specimen	Stiffener type	Pu (kN)	Enhancement %
DS0	-	175.840	-
DS1	Internal ring	284.750	41
DS2	Shear studs	532.776	200
DS3	Reinforcing bars	572.121	225

3. CONCLUSION

In this review, all publications related to the topic of CFDST column strength improvements were collected. Through which perception was given about the methods of improvement and the percentage of increase in the strength. It is noticeable that all of this research focused on two topics. The first is the process of internal and external confinement of the concrete layer. Second, the contact areas between concrete and steel tubes All researchers focused on improving the two important topics in different ways, and through this, we can conclude the following:

1. The improvement of confinement by external rings may be the alternative of using thin steel tubes with external confinement instead of the conventional thick CFDSCT.
2. The external confinement of the outer steel tube forms a good efficiency to obtain improved load-carrying capacity.
3. The internal stiffeners on the inner tube are strengthening the bond in a good way, with some minor increase in carrying capacity and good ductility before the failure.
4. The load-capacity of a column is unaffected significantly by the replacement of the exterior steel tube with FRP. It also makes the implementation process more difficult. But it only increased the capacity when it was used as an external confinement for the outer tube.
5. The strength of the CFDST column is more influenced by the usage of steel bars welded longitudinally to the inner tube than by those welded to the inner interface of the outer tube.

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