Assessment of Concrete Filled Steel Tubular Members: An Experimental Review

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Abstract In this world with rapid development, durable and fast construction techniques lead to the invention of composite materials that are robust and advantageous over conventional materials. Recently invented Concrete-filled steel tubular members are the composite members used in civil engineering works to replace conventional steel and concrete members. This paper deals with an overview of the experimental performance of various types of composite members such as columns, short columns, stub columns, beam-columns, and slender columns deals with various loads such as axial compression, flexural load, cyclic bending, long-term sustained load, torsional load, and impact load. Effects due to the variation in the parameters like steel and concrete strength, diameter to thickness ratio, axial load level, shapes of tubes of these composite members on load-carrying capacity, flexural stiffness, ductility, torsional capacity, and cyclic performance of these members are discussed in this paper. The future scope is mentioned for study related to these composite members in the paper.

Keywords: - Concrete filled steel tube members, Composite members, CFST, CFDST, CFSST

1. Introduction
Different sorts of materials are utilized in various types of infrastructural development. They are steel, sand, water, and aggregates. A material called reinforced concrete benefits all these elements used to construct buildings, dams, and various types of works. New building materials known as composite materials have become popular and widely employed nowadays because these materials have superior qualities to constituent materials. Thus, these composites have benefits over their constituents. The CFST (concrete-filled steel tubular member) material component is employed in recent days as a substitute for conventional structural members. The benefits of the CFST members include high compressive strength, more excellent fire resistance, improved ductility, and high energy dissipation capability. CFST is an alternative for regular columns, bridge piers, pylons, and pressure pipes, because of these benefits (‘).

Furthermore, these members do not require any formworks that reduce the construction time, material and labour expense, and improvement of members’ efficiency. For more than 60 years, an extensive study on CFST members has been conducted in China, Europe, Japan, and London (U.K.). The nations where CFST members are widely employed for different sorts of applications have published CFST member’s codes of practice such as Japanese code (AIJ 2008), American code (ANSI/AISC 360–10, 2010) Chinese code (DBJ/T13-51 2010), British code (BS 5400-5 2005) and European code (Eurocode 4 2005). Researchers developed a novel CFDST composite component (Concrete-Filled Double Steels Tubular members). This composite element is composed of 2 concentrated concrete and steel tubes is in the area between the 2 steel tubes and the inner space of the internal steel tube as a hollow part.
This member has a comparable but superior quality than that of CFST, including higher stiffness, more excellent stability and usable space from the inner steel tube, more excellent damping, improved stiffness, and higher cyclic loading performance. This paper evaluates the literature review conducted on CFDST member’s research. This paper offers a clear description of the experimental and review studies carried out on CFDST members. The publications on CFDST are investigated, and the methods employed in different research papers for scientific investigation, research benefits, and research findings are highlighted. In recent years, researchers have investigated several types of composites in the families of tubular filled concrete structures, such as the CFST, CFDST, CFSST (concrete-filled stainless-steel tubular member), owing to benefits and uses, and their assessment is shown below.

![Figure1. Typical cross-sections of CFST and CFDST (Ekmekyapar and Ghanim Hasan 2019).](image)

2. Literature Survey
(Han et al. 2014) published a paper associated with the entire research work on the family of concrete-filled Steel tubular columns up to date and further scope for the research related to CFST members. This research paper explains detail description of, how the family of concrete-filled steel tubes was developed is discussed in depth. Materials used to construct concrete-filled steel tube members such as steel and concrete with their selection criteria are described. Research framework, static, dynamic, and fire performance, construction, and durability difficulties associated with concrete-filled Steel tube members are also explored by analyzing past research. The CFST member's design criteria are addressed concerning American code, Chinese code, Eurocode, and Japanese code. Few construction application examples of CFST in buildings, bridges, and other structures such as service stations, electrical pylons are also covered. Finally, it was established that CFST could be utilized as a replacement for steel and RCC systems. The feasibility of the CFST members is also examined. And a future scope is also indicated relating to life cycle performance evaluation and high-performance material usage for the betterment of the CFST members.

(Gardner 2019) presented a review paper on the stability and design of stainless-steel structures. In this paper, he has studied and presented stress-strain responses of prominent families of stainless steel such as duplex, austenitic and ferritic Steel. Consideration of material non-linearity in steel structural design is discussed in this paper. Material non-linearity at the cross-section, member, and frame-level are studied comparatively. The first-order elastic analysis used to design steel members, its disadvantages, and alternative approach to design steel members by considering geometric and material non-linearity is also discussed at the end stainless steel 3D printing application, and execution is elaborated.

(Han et al. 2019) illustrated research on a thorough study of material characteristics of stainless steel and study of the performance of CFSST columns and joints at standard temperature and elevated temperatures. The stress-strain relationship for stainless steel based on previous research is expressed in the form of the equation. Comparing the different types of stainless steel considering the Eurocode, American code, and Chinese code has been made. Study on residual stresses, the effect of strain rating, stress-strain performance under fire loading, and post-fire stress-strain relationship is represented graphically. Bond-behavior between concrete and steel tubes, static, dynamic, and fire performance, along with the study on composite columns' joints, is also discussed. This study concluded that the American code, Eurocode, and Chinese code gives less accurate estimate of ultimate load capacity of CFST columns with carbon steel tubes. Performance-based study of CFST column with no heat isolation is to be studied suggested for future work.
3. Review on Experimental study
A review on experimental studies carried out related to concrete-filled steel tubular composite members is tabulated below. From the table, it is easy to recognize the effects of the parametric changes on the properties of these composite members.

**Table 1. Overview of Experimental Studies on Concrete Filled Steel Tubular Composites.**

| Sr. No. | Authors | Tested specimens | Tests performed | Aim of the study | Specimen’s section type | Varied Parameters | Conclusion |
|---------|---------|------------------|-----------------|------------------|-------------------------|------------------|------------|
| 1       | (Zhao and Grzebieta 2002) | CFDST stub columns | Compression and Bending tests | Theoretical model development for prediction of ultimate strength of stub columns. | Both internal and external skin square hollow sections (SHS) | Width to thickness ratio | Improvement in ductility is recorded for CFDST as compared to CFST when the members subjected to compression and bending. A concrete model to predict collapse mechanism is suggested, and it shows good agreement with experimental results. |
| 2       | (Zhao et al. 2002) | CFDST stub columns (by considering confinement effect) | Axial compression test and plastic mechanism | Prediction of collapse behavior of stub columns byperforming plastic mechanism analysis. | Both internal and external tubes were square hollow sections (SHS) | Maximum strength model (unconfined, confined, and full-strength models) | |
| 3       | (Susantha et al. 2005) | Fabricated steel column (stiffened or unstiffened LYS steel plates) | Cyclic lateral loads, constant axial load. | To analyze the ductility improvement of bridge piers. | Standard strength steel plates with nominal yield stress | LYS steel plates attachment | Enhancement in overall buckling, ductility found in LYS stiffened plates. |
| 4       | (Tao and Han 2006) | CFDST stub columns, beams, and beam-columns(by considering confinement effect) | Axial compressive loading. | Determination of load-carrying capacities of composite members. | Internal and external tubes circular hollow (CHS) | Slenderness ratio and eccentric load | Enhancement in ductility and strength observed CFDST RHS internal and external members. |
| Sr. No. | Authors                  | Tested specimens          | Tests performed                  | Aim of study                                                                 | Specimen section type | Varied Parameters                                                                 | Conclusion                                                                 |
|--------|--------------------------|---------------------------|----------------------------------|-------------------------------------------------------------------------------|-----------------------|----------------------------------------------------------------------------------|----------------------------------------------------------------------------|
| 5      | (Han et al. 2006)        | CFDST Beam-columns        | Axial loading (constant) and flexural loading (cyclically increasing) | Prediction of the seismic performance of CFDST beam-columns.                   | External SHS and internal CHS and few CHS internal as well as external | Axial load level and strength of core concrete                                 | Energy dispersion and ductility of the members with CHS is greater than those of SHS. |
| 6      | (Zhao et al. 2010)       | CFDST stub columns        | Axial loading with large deformation | To check out load carrying capacity and energy absorption.                    | Internal and external skins CHS | D/t (dia. To thickness ratio)                                                     | Enhancement of load-carrying capacity by Five times and increment in the energy absorption By fourteen times. |
| 7      | (Han et al. 2011a)       | CFDST column              | Long term sustained loading      | To investigate the CFDST column's performance subjected to sustained loading (long-term) and develop a simple formula for predicting the ultimate strength of the CFDST column subjected to sustained loading. | CHS outer as well as inner tube and rectangular outer and circular inner tube | Tube strength, specimen length and D/t ratio of internal tube | Increment in hollow ratio resulted in enhancement of strength index of CFDST. Long-term sustained loading results in an increment of deformation and decrement of the CFDST column's ultimate strength. |
| Sr. No. | Authors | Tested specimens | Tests performed | Aim of study | Specimen section type | Varied Parameters | Conclusion |
|--------|---------|------------------|----------------|-------------|-----------------------|-------------------|------------|
| 8      | (Han et al. 2011b) | Stainless steel-concrete–carbon steel double-skin tubular (DST) Column (stub) | Compressive testing | To check the effect of the cross-section. The inclination and tapering angle on the composite columns. | Circular, square, round-end rectangular and elliptical cross-sections | Type of section (circular, square, elliptical), Type of column (straight, inclined, tapered) And the hollow ratio of the column | Tested stub DST columns Failed due to outward buckling (local) experienced by outer tubes and the Inward buckling experienced by the internal tubes. In case of inclined DST columns, increase in tapered angle of inclined tapered DST column resulted in strength decrement. |
| 9      | (Yang et al. 2012) | CFDST members | Partial compressive load | To derive a simplified method for bearing capacity estimation of CFDST members. | CHS internal as well as external tubes and SHS internal as well as external tubes. | Thickness and hollow ratio and the of upper endplate, compression area ratio of tubes | The bearing capacity factor (K_{bc}) of circular CFDST members are nearly 2 times square CFDST members. Increment in thickness of upper end plate resulted in increment of whereas decrement in compression ratio resulted in increase of K_{bc}. |
| Sr. No. | Authors | Tested specimens | Tests performed | Aim of study | Specimen’s section type | Varied Parameters | Conclusion |
|--------|---------|------------------|-----------------|-------------|------------------------|------------------|------------|
| 10     | (Yuan and Yang 2013) | Concrete-filled double skin composite tube columns (CFDSCT) | Axial compressive loads | To predict ultimate axial compressive capacity of CFDSCT | Octagonal steel tube as its external skin, and circle PVC-U pipe as its internal skin | Strength of Concrete, R/t proportion, hollow section ratio, and slenderness ratio | Increment in concrete strength resulted in increase of the ultimate axial load carrying (compressive) capacity of the CFDSCT column. |
| 11     | (Huang et al. 2013) | Concrete-filled double skin steel tubular (CFDST) members | Torsional load | To investigate the theoretical and experimental performance of the CFDST column when subjected to pure torsional force. | CHS as Both internal and external tubes and CHS internal tube and SHS as the External tube | The shape of the component, hollow ratio, and steel ratio | Increment in Hollow ratio and steel ratio increase torsional capacity. |
| 12     | (Ho and Dong 2014) | CFDST columns with external confinement | Uniaxial compressive load. | To analyze the CFDST ring-stiffened columns’ uniaxial performance in load-bearing capacity, elastic stiffness, and ductility. | Circular-shaped CFDST specimens, both internal and external tubes | Spacing (position) of external steel rings in multiples of dia. of external steel tubes | Installation of steel rings as external confinement resulted in improvement of stiffness, ductility and elastic strength of members. |
| Sr. No. | Authors | Tested specimens | Tests performed | Aim of study | Specimen section type | Varied Parameters | Conclusion |
|--------|---------|------------------|-----------------|-------------|----------------------|------------------|------------|
| 13     | (Essopje e and Dundu 2015) | Concrete-filled circular slender tubes (CFDSCT) columns | Axial compressive load (till failure) | To develop new formulas for Strength outcomes of CFDSCTs. | Concrete-filled circular tubes (CFDSCT) columns | Length, diameter, and strength of the outer steel tubes | New formulas were developed to determine the strengths of the CFDSCTS. |
| 14     | (Wang et al. 2015) | Concrete-filled with dual steel tubular (CFDST) components | Drop weight impact with low velocity | To investigate the residual failure modes and the time history of the impact forces, the global deformation, and strains of concrete-filled with dual steel tubular (CFDST) components. | Concrete-filled with dual, i.e., both external and internal skin of steel and tubular shape (CFDST) | The column's shape (straight and tapered), the boundary conditions (simply supported and fixed), impact energy and the axial load level | All CFDST members showed ductile manner, and the residual deformation consisted of local deformation at the impact section and total bending deformation. |
| 15     | (Hsiao et al. 2015) | Concrete filled steel tubular members’ (CFT) and CFDST columns using ultrahigh-strength steel | Flexural cyclic load along with an axial compressive load | To determine the seismic capacity of CFT and CFDST columns made with ultrahigh-strength steel. | Circular internal as well as external skin | Thickness diameter of internal steel tube and concrete grades | Simple models for load vs. displacement and moment vs. curvature have been developed and proposed. |
| Sr. No. | Authors                  | Tested specimens          | Tests performed                  | Aim of study                                                                 | Specimen section type                                                                                           | Varied Parameters                                                                                       | Conclusion                                                                                                                                 |
|--------|--------------------------|---------------------------|----------------------------------|-------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------|
| 16     | (Ye et al. 2016)         | Concrete-filled bimetallic tubes (CFBT) | Axial compressive load | To explore the effect of the variables on failure mode, load versus deformation correlation, axial compressive strength, and the specimen's strain advancement. | The exterior skin of the stainless-steel tube and the inner skin of the carbon steel tube | The thickness of the stainless-steel tube skin and strength of the in-filled concrete | The effectiveness of current design standards to calculate the axial compressive capacity of CFBT when subjected to axial compression was analyzed. |
|        |                          |                           |                                  |                                                                               |                                                                                                               |                                                                                                      | The result indicates that the internal tube's contribution to the axial capacity of the long column is less than the estimated value since the column undergoes elastic bending until it yields. |
| 17     | (U. M. And S. A. 2017)   | CFDST, CFST, and Concrete Filled Hollow Single Skinned Steel Tube (CFHSST) | Axial compressive loads         | To develop axial capacity formulas for long column CFDST sections are depending on the strength superposition design technique. | CFDST, CFHSST cross-sections. (SHS section for external skin and square, circular for inner skin) | The shaft's length, the shape of the internal tube, and the internal tube's absence | UHSC as concrete infill on CFDST is beneficial since secondary effects in slender columns result in no significant improvement of bearing capacity. |
| 18     | (Ibañez et al. 2017)     | CFST and CFDST            | Eccentric loading               | To study the effect of ultra-high-strength concrete (UHSC) on the mechanical response of CFDST. | Thick, thin combination of steel tubes for internal and external skin | Positions of the external tube and internal concrete core and thickness of steel tube |                                                                                                                                                  |
| Sr. No. | Authors | Tested specimens | Tests performed | Aim of study | Specimen section type | Varied Parameters | Conclusion |
|--------|---------|------------------|----------------|--------------|-----------------------|------------------|------------|
| 19     | (Ye et al. 2018) | Concrete-filled bimetallic tubular (CFBT) stub columns | Compression loading | To study the behavior of square CFBT columns subjected to axial compression, its failure pattern, P-delta response, and ultimate strength estimation also establishment of a 3D FEA model for CFBT square stub columns under axial compression. | Stainless steel and carbon steel square tubes | Steel grades, Stainless steel tube compressive strength and thickness of concrete cube | The axial compressive strength of CFBT varies linearly with concrete grade. Increase in wall thickness of stainless-steel results in an increase in axial compressive strength of CFBT. |
| 20     | (Zheng et al. 2018) | Double-tube concrete-filled stainless steel tubular (CFSST) | Constant axial compression and variable cyclic loading in the lateral direction. | To evaluate the performance of double-tube CFSST subjected to axial compression and cyclic loading in the external skin as well as internal level, diameter ratio (inner to the outer tube) and the existence of internal concrete | Circular internal as well as external skin | Axial load level, diameter ratio | Stiffness reduction occurs with an increase of axial load level, but it remains unaffected by diameter ratio. |
| Sr. No. | Authors | Tested specimens | Tests performed | Aim of study | Specimen section type | Varied Parameters | Conclusion |
|--------|---------|------------------|-----------------|--------------|-----------------------|-------------------|------------|
| 21     | (Chen et al. 2018) | Square CFSST stub columns | Axial compression with elevated temperatures | To study the response of square concrete-filled stainless steel tubular stub columns after exposure to elevated temperatures under axial compression. | Square section for internal as well as external tubes. | Temperature and thickness of columns, concrete strength, and cooling techniques | Temperature is the parameter that has a substantial influence on the ultimate load-bearing capacity of the columns. Deformation vs. load curve shows linear behavior on increasing concrete strength. |
| 22     | (Ekmeky apar and Ghanim Hasan 2019) | CFDST columns | Compression load | To investigate the influence of the internal steel tube on the mechanical response of CFDST columns compression. | Internal as well as external steel tube of circular shape | Depth to thickness ratio of steel tubes and grades of concrete | Internal tubes offered percentage increase in the range of 18.95–65.44 in compressive strength. Eurocode givers better and closer result for compressive strength of tested specimens, whereas American codes overestimate the capacity. |
| 23     | (Wang et al. 2019) | CFDST column | Axial compressive load | To evaluate the effectiveness of the present European and American design code provisions for CFDST design. | The internal skin of square-shaped carbon steel and external skin rectangular stainless steel | The shape of the concrete strength, cross-section, and dimensions of tubes of the infill | |
| Sr. No. | Authors | Tested specimens | Tests performed | Aim of study | Specimen section type | Varied Parameters | Conclusion |
|--------|---------|------------------|-----------------|-------------|-----------------------|-------------------|------------|
| 24     | (Yan and Zhao 2020) | CFDST short column | Axial compressive loading | To estimate a reliable novel formula for determining the compressive strength of CFDST short column by considering the broad range of parameters. | Circular internal as well as external skin | The thickness of inner and outer tubes, grades of concrete | A novel strength design formula was developed to estimate the compressive strength of CFDST short circular columns. |

4. Conclusion

Concrete-filled steel tubular members are instrumental in rapid and practical construction. These composite members give better performance when subjected to various types of loadings. So, these members are the better alternatives for conventional members like steel and RCC members. The literature survey observed that most of study had been done to increase the strength, ductility, flexural strength, stiffness, and torsional stiffness of these composite members. Particularly for CFDST members with internal steel tube significant increase in compressive strength is observed. Significantly less work is available on the nonlinear analysis of these composite members. So, it is intended to carry out nonlinear analysis by considering various types of nonlinearities for these members to predict the failure patterns and safety of these members for better performance and durability.

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