STATE OF THE ART ON CONCRETE FILLED STEEL TUBULAR COLUMNS

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Abstract

Understanding the behaviour of concrete filled steel tubular (CFST) members give rise to many structural benefits for the community. Last few decades, increasing recognition has been given to the structural performance of CFST members and their applications. CFST members are considered to have more ductility and strength than their Reinforced Cement Concrete (RCC) counterparts. Currently, only a handful of countries have adopted CFST members in their structures. This paper comprises of two parts, first portrays the origin, initial developments of CFST members. Secondly the various studies conducted on CFST columns are addressed comprehensively.

Keywords: *Concrete Filled Steel Tube (CFST), Reinforced Cement Concrete (RCC), strength, ductility.*

1. Introduction

A structural member composed of two or more dissimilar materials is called composite members. Since they exhibit multiple properties, composite member has superior properties as compared to individual materials. There are many such composite materials available in the market and are used in the industry. Mostly used composite material in the construction industry is the steel-concrete composites. Concrete is strong in axial compression but weaker in tension whereas steel is very strong in tension. Thus, a composite made out of this will be able to take up compression and tension effectively.

Concrete filled steel tubular (CFST) structure uses the benefits of both the hollow structural steel and the concrete core. The composite action improves its structural system behaviour. CFST members possess high strength, high ductility, large energy absorption capacity than the reinforced concrete members. During axial compression the concrete inside the hollow steel gets confined thereby increasing its resistance to applied loads and its ductility. CFST members exhibit ductile failure mechanism due to its high shear capacity.

Concrete – filled steel tube (CFST) columns are extensively used in modern structures, mainly due to the combined advantages of the steel tube and the concrete core. However, many researchers cast doubt on the use of plain concrete as in-fill material in steel tubes, due to the extremely disastrous effects of the 1995 Kobe earthquake in Japan on steel and concrete composite structures. This prompted a change of seismic design perspective from the previous emphasis on structural strength to emphasis on structural ductility and energy absorption capacity. Accordingly, the in-fill material inside steel tubes is required to be of the quality as to increase the ductility and energy absorption capacity of composite columns. Many kinds of in-fill materials are used to improve ductility of composite columns. One such infill material commonly used is concrete. Concrete-filled steel tubes (CFSTs) possess the superior mechanical properties of high bearing capacity, good plasticity, and toughness, with the advantage of convenient construction suitable for modern engineering technology. CFSTs also satisfy the structural requirements for high-rise buildings, large-spans bridges, heavy load structures, and construction in harsh environments. Thus, CFSTs are widely used in high-rise and super-high-rise buildings, industrial plants, long-span bridges, and underground structures, providing good economic benefits and construction effects.

Concrete-filled steel tubes (CFSTs) are used in bridge applications as columns and shafts, providing superior structural performance and ease of construction. Such advantages are primarily because the CFST eliminates the need for embedded reinforcement and supporting formwork. The use of CFST in bridges is permitted according to the AASHTO LRFD Bridge Design Specifications (AASHTO 2017). However, despite great promise, CFSTs have not been widely used across the continents, mainly due to the absence of an established design guideline and construction practice. In recent years, CFST columns have been mostly used in continuous rigid frame bridges. One example is the super large Labajin Bridge in China, in which the column height exceeds 180 m.

2. Codal Provisions Used

- American Concrete Institute (ACI 318-19)
- Load and Resistance Factor Design Method (AISC-LRFD)
- Architectural Institute of Japan (AIJ)
- British Standard (BS 5400-Part 5)
- Sans 10162-1(South African Code)
- Chinese Code (CECS 28: 2012)
- European Committee for Standardization (Euro Code 4)

3.Improvement of Structural Performance

Due to material properties:

- The steel tube acts as an external reinforcement. The steel ratio in the CFST cross section is much higher than those in the reinforced concrete sections.
- Steel of the CFST section is well plasticized under bending since it is located on the outside of the section.
- The improvement of properties of the concrete in-fill is enhanced due to confinement pressure exerted by the steel tube.

- The characteristic buckling problem of thin-walled steel tubes is controlled due to the presence of the concrete in-fill and the strength deterioration after the local buckling is decreased due to the restraining effect of concrete.
- Shrinkage and creep of concrete are much smaller than ordinary reinforced concrete.
- **Due to Geometrical properties:**
- It provides the maximum stiffness as the material lies farthest from the centroid and provides the greatest contribution to the moment of inertia.
- The steel as the outer part of core concrete performs most effectively both in tension and bending. Whereas the concrete core gives the greater contribution to resisting axial compression.

4.Historical developments:

Many studies have been carried out to investigate the behaviour of CFST columns subjected to various types of loadings. Furlong (1967), Knowles and Park et al (1969), Neogi et al (1969) and Tomii et al (1977) aresome of the earliest researchers who studied the behaviour of concrete filled steel tubular columns subjected toconcentric compression and observed that the compressive strength enhances due to concrete confinement andthe yield strength of steel tube decreases due to the development of hoop stresses in the steel tube.

In past two decades, experimental and theoretical studies, researchers concluded that the ultimate loadof circular CFSTs is significantly larger due to the confinement of the concrete and strain hardening of the steel.Knowles and Park (1969) proposed a value of 44 for KL/r (the ratio of effective length to radius of gyration)approximately equal to L/D of 12. Above this value confinement does not occur. Bridge et al (1995) haveagreed with a slenderness ratio equal to 15 as this boundary.

Many research projects on the ultimate capacity of rectangular CFST columns have also been carried.Fujimoto et al. (1995) and Uy (2001) carried out an experimental study for square CFST columns with highstrength steel. Furthermore, Uy (2001) investigated the effect of local buckling due to geometrical imperfectionsand residual stresses. Han (2002) performed tests on 24 rectangular short composite columns with varying H/t orB/t and L/H and concluded that the ultimate capacity was influenced by the confining factor, material propertiesand aspect ratio.

The square/rectangular columns are preferred over the circular columns by the designers due toarchitectural reasons despite of their excellent mechanical behaviour because of more effective the confinementeffect and better post-yield behaviour than square CFST columns (Schneider,1998). Most importantly the beamto column connection is more convenient for square/ rectangular CFST columns than for circular columns,and the stiffness of square CFST columns is more than circular columns with a same sectional size as a whole.

Liao *et al*. (2017)conducted experimental study on the behaviour of concrete filled stainless steel tube (CFSST)under lateral cyclic loading. They conducted experiments on CFSST columns with constant axial load and increasing cyclic flexural loading. They varied certain parameters which are axial load, cross sectional type, and concrete type. They investigated the influences of these parameters on the strength, ductility, stiffness, and energy dissipation system. It was found that CFSST columns exhibited excellent energy dissipation and ductility, even when the specimens were subjected to high axial loads.

Saini et al. (2019) evaluated the performance of concrete filled steel tube bridge columns subjected to vehicle collision. The performance of a set of CFST piers was studied through detailed numerical simulations. Upon validation of the developed FE models with the experimental test results, comparisons were made with the RC piers of equivalent sections under vehicle collision. For this purpose, various performance measures, such as impact force time history, deformed shape, maximum shear force, maximum column displacement, PDF, and ESF, were examined.Based on simulation results, CFST piers were found to perform significantly better than their RC counterparts. This conclusion was made based on the observation of no major damage in the CFST pier, whereas the RC pier of the same size experienced extensive damage, and even collapse, under high impact velocities. The superior performance of CFST piers was primarily due to the confinement effect provided by the steel tube.

Song *et al*. (2021)investigated the collapse behaviour of concrete filled steel tubular column steel beam frame under impact loading. Progressive collapse of a concrete-filled steel tubular (CFST) frame structure is studied subjected to impact loading of vehicle by the finite-element software ABAQUS, in the direct simulation method (DS) and alternate path method (AP), respectively. A finite-element analysis (FEA) model is established to predict the impact behaviour of a five-storey and three-span composite frame which was composed of CFST columns and steel beams under impact vehicle loading. Failure mode, internal force-time curve, displacement-time curve, and mechanical performance of the CFST frame were obtained through analysing. Finally, it is concluded that the result by the DS method is closer to the actual condition and the collapse process of the structure under impact load can be relatively accurately described.

Sandeep *et al.* (2021)conducted experiments to study the mechanical behaviour of silica fume concrete filled steel tubular composite column. For the study, variability in steel tube thickness and column height with a constant diameter are considered. To explore the influence of silica fume in concrete, microstructural analyses are carried out by SEM, XRD, and FTIR. The experimental results reveal that the use of silica fume as a replacement of cement is feasible. The silica fume concrete-filled steel tubular (SCFST) column has marginal enhancement strength capacity compared to CFST column as thickness increases. The results showed that the optimum replacement of silica fume in concrete is 10%. It also showed increase in compressive strength of about 11.51% as that of conventional concrete. XRD results confirmed the presence of quartz compound which helped in the strengthening of concrete mix. The disintegration of Si and AL was found from the XRD tests.

Wu *et al*. (2021)did an experimental study of UHPC encased concrete filled tubular column. They subjected the CFST columns to axial compression loading. It was found from the experiments that the UHPC encased CFST columns was less damaged than the encasing ordinary concrete of OC-CFST columns and did not spall when the UHPC was crushed. The UC-CFST stub columns reached their ultimate load-bearing capacity when the encasing UHPC attained the peak compressive strain, which was much greater than that of the OC-CFST stub columns. Compared to the OC-CFST stub columns, the ultimate load-bearing capacity of UC-CFST stub columns improved markedly by 75%–289% and the compressive stiffness increased by 22%–49%, while the ductility decreased by about 50% on average. The failure mode of the UC-CFST stub columns was different from that of the OC-CFST stub columns under axial compression. When subjected to destructive axial compressive loads, significant crushing and spalling of the encasing ordinary concrete of OC-CFST columns occurred. On the other hand, the encasing UHPC in UC-CFST columns was damaged less than the ordinary concrete of the OC-CFST columns and did not spall when crushed.

Manikandan *et al.* (2021) studied the performance of concrete filled steel tube with different infills. The infills chosen were conventional concrete, steel-fibre reinforced concrete, geopolymer concrete, expansive concrete respectively. The concrete was all of the same grade. Specimens were casted and cured using both water and a self-curing agent. Self-curing is the only way possible in the case of infilled concrete was found to have no influence on the strength of the concrete from the study. Analytical investigations were carried out using EUROCODE4 for the load carrying capacity under axial compression. Axial compression loading tests were performed on the CFST columns and results were obtained. It was found from the study that the expansive concrete exhibited higher bond strength and higher axial compressive strength. This increase in strength may be attributed to the addition of shrinkage compensating admixture.

5. Gaps in the research area:

Many researchers have proved the usefulness of CFST columns as columns whereas many have testedthese sections under flexural loads successfully and concluded that filling of steel tube with concrete enhancesthe flexural strength, moment carrying capacity and stiffness. But CFST sections have not been tested for enough for impact and cyclic loading. The literature available reveals that all the studies available on CFST column does not deal with the performance of the column under combination of loading.

It has been observed from the literature review that relatively few researchers have performed finiteelement analysis of square/rectangular CFST sections subjected to different loading conditions. So, there is a requirement of FEM based numerical modelto model and investigate the true behaviour of these incredibly useful sections.Finite element methods are the most effective way to study the behaviour of CFST structures becausethe experimental method is highly expensive and time-consuming even though it provides dependable resultsabout the performance of CFST structures. Hence, more studies are required for the development of such kind ofmethods. The behaviour ofCFST columns with different infills subjected to different loading conditions is not fully understood hence the requirement for accurate andreliable analysis is needed.

6. Conclusions:

The paper discusses the basic properties and theoretical information about the behaviour of CFSTcolumns, in brief. The paper also includes the few researches which include the application of CFSTcolumns around the world. In India use of steel buildings is still at nascent stage. The cost factor is the maininfluencing factor behind. It can be concluded that in today’s scenario, when green buildings have become thefocus of designers, CFST structures can be a better alternative to traditional structures of concrete and steel. In order to achieve that extensive research is needed in the area of CFST under all circumstances.

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