Behavior of Concrete filled Steel Tubular Column under Fire: A Review

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Abstract - *The use of concrete filled steel tube (CFST) columns offers an alternative for providing the required fire resistance and load bearing capacity, making its use in medium and high-rise structures are highly popular. This paper aims to review the previous studies on CFST column under fire. The design of the CFST column is summarized with previous investigations on experiments and numerical modelling at ambient temperature and elevated temperature. Different conclusions were drawn depending on the material's properties, considered parameters and the method used for the investigations. Outer diameter or width of the steel tube, steel tube thickness, concrete grade, column length, and eccentricity of loadings are among the parameters that affects the structural behaviour of CFST columns under fire. Several numerical analysis software was adequately used for simulating the behaviour of CFST columns at elevated temperatures, and validated using experimental results.*

***Key Words*: CFST Column, Elevated temperature, Fire performance, Stress-Strain, Finite Element Model (FEM).**

1.INTRODUCTION

Fire is one of many severe environmental conditions. When a structure is exposed to fire, the members are gradually weakened and will eventually fail, causing the whole – or part – of the structure to fail. A typical example is the collapse of the Twin towers in New York, USA as a result of terrorist attack on September 11, 2001 [1]. In order to minimise loss due to a fire, buildings should be designed in such that it is able to withstand fire for a certain period, also known as fire resistance designs. During a fire, the moisture in the concrete will gradually turn into steam at 100°C. An explosive spalling (pop-corn cracking) of the concrete will occur when the pressure builds up and these steams are unable to dissipate quickly through the microstructure of the concrete [2]. Concrete filled steel tubular (CFST) columns integrate the appropriate characteristics of concrete and steel materials, therefore providing the advantages of high ductility, high stiffness and strength, great energy dissipation, considerable economy and high speed of construction [3]. The fires are categorised into accidental fires, arson fires, terrorist attack fires, and natural disaster fires [4]. Fire safety provisions are specifically for accidental fires [5]. Structural fire safety is the least developed within the field of fire science [6], yet remains as an important consideration in the design and maintenance of a building [7]. Nevertheless, new construction materials such as fibre-reinforced polymers [7], foamed concrete, geopolymer concrete or composite materials are being applied in building system where it has a little of references can be obtained from its fire resistance properties.

2. BASIC TERMINOLOGY

CFST Column: Concrete Filled Steel Tubular Column does combine the advantages of concrete and steel. The strength of filled concrete can be enhanced by the confinement effect provided by the steel tube, while the local buckling of the steel tube can be delayed or even prevented by the concrete core. Moreover, the steel tube can serve as a permanent formwork for concrete casting and thus the construction period can be shortened and the cost can be reduced. The cross-sections for the CFST are various and circular, square and rectangular sections are commonly adopted in engineering design. Basically, only plain concrete was used to fill the steel tube. Sometimes in order to improve the strength and ductility of concrete, glass or steel fibres will be added to the concrete. In addition, steel bars or I-section steel can be encased in the concrete core to improve the resistance as well as reduce the section sizes. In general, CFST columns are better than conventional steel and columns in terms of fire resistance, due to the fact that the concrete can absorb the heat from the steel tube while the steel tube can prevent the concrete from spalling.

SPALLING: Spalling is a term used to describe areas of concrete which have cracked and delaminated from the substrate. There are a number of reasons why spalling occurs including freeze thaw cycling, the expansive effects of Alkali Silica Reaction or exposure to fire. However, the most common cause of spalling is the corrosion of embedded steel reinforcement bars or steel sections.

FINITE ELEMENT METHOD: The finite element method (FEM) is a numerical technique for finding approximate solutions to boundary value problems for partial differential equations. It is also referred to as finite element analysis (FEA). FEM subdivides a large problem into smaller, simpler, parts, called finite elements. (Which is also called discretization). The simple equations that model these finite elements are then assembled into a larger system of equations that models the entire problem. FEM then uses variational methods from the calculus of variations to approximate a solution by minimizing an associated error function. Nowadays softwares like ANSYS, ABAQUS, HYPERWORKS etc are used to complex problems.

3. LITERATURE REVIEW

In the mid of 2000, fire performance tests of CFST columns were carried out by National Research Council of Canada under the support of Canadian Institute of Steel Construction (CISC) and American Iron and Steel Institute (AISI) [8, 9, 10]. The temperature curve of fire tests followed ASTM E-119. The research studies clearly demonstrated that the use of carbonate aggregate in concrete-filling provided about 10% higher fire resistance than siliceous aggregate. A higher fire resistance was obtained with circular CFST columns than with square CFST columns having the same cross-sectional area.

Han [10] presented experimental results of 13 circular specimens including eight without fire protection and five with fire protection as shown in fig (1). Han [11] presented experimental results of three square and eight rectangular specimens with or without fire protection subjected to axial or eccentric loads. The column height, cross-sectional dimension, and the thickness of fire protection material had significant influence on the fire resistance of the columns. The fire resistance of the CFST columns, with high load ratios, could be enhanced through the use of a fire protection coating. The influence of the load eccentricity ratio on the fire resistance of the column was insignificant when the column had a constant load ratio. be used. Other font types may be used if needed for special purposes.

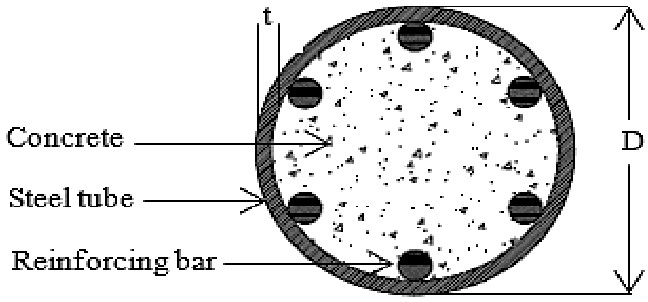

Figure (1) Typical cross-section of column

Kodur [12] reported the results of eight full-scale fire resistance experiments of high strength specimens. The main study variables were the column dimensions, load intensity and concrete reinforcement. The behavior of high strength CFST columns was significantly different from that of normal strength CFST columns. The fire resistance of high strength CFST columns could be significantly improved by adding steel fiber reinforcement to concrete. The fire resistance of high strength CFST columns with high loading levels could be enhanced through the use of conventional bar reinforcement.

Figure (2) Machining of steel tubes

Lu [13] reported an investigation into the behavior of high strength self-consolidating CFST stub columns exposed to standard fire. The behavior of high strength self-consolidating CFST stub columns exposed to standard fire was almost the same as that of conventional CFST columns. All stub columns failed in a ductile way. Specimens retained their integrity after testing despite of local bulge of the steel hollow section and local crush of the concrete.

Romero [14] and Moliner [15] reported fire tests of slender CFST columns filled with normal and high strength concrete, subjected to concentric axial loads and eccentric axial load, respectively. For slender columns subjected to high temperatures, the behavior of high strength concrete was different than for stub columns, spalling not being observed in the experiments. Furthermore, the addition of steel fibers was not found very advantageous in slender columns under concentric axial loads. The addition of steel fibers did not improve the fire resistance of slender columns under eccentric loads, as compared to columns filled with plain concrete. However, the addition of reinforcing bars increased the fire resistance of the columns in this situation.

Yang [16, 17] reported experimental results of square and rectangular CFST columns subjected to non-uniform fire exposure by using furnace shown in fig (2). The number of sides exposed to fire had significant influence on the Applied Mechanics and Materials Vols. 638-640 1399 thermal distribution. For square specimens subjected to a 1-sided exposure and 3-sided exposure, the thermal distribution was uniaxial symmetric and the lowest temperature area was closer to the side unexposed to fire rather than in the cross-sectional center. The fire resistance of the CFST columns increased considerably with the decreasing number of sides exposed to fire and decreasing load ratio, while load eccentricity had moderate influence.

Figure (3) The utilized furnace

Lu [13, 18] reported experimental results of stub and full size self-consolidating concrete-filled double skin tubular (CFDST) columns during the standard fire test. For stub columns, the fire resistance of CFDST columns increased with the decreases in load level especially for those filled with fiber reinforced self-consolidating concrete. The use of steel fiber in the self-consolidating concrete could significantly increase the fire resistance of CFDST columns when the load level is below 0.6. CFDST columns could have better fire endurance than unfilled and CFST columns.

Kan Zhou [19] studied group of eccentrically loaded concrete-filled steel tubular (CFST) columns with and without IFC protection was tested in standard fire circumstance up to 180min. Three types of intumescent materials were adopted and different dry film thicknesses of the fire coating were designed. He found out that with the protection of the given DFTs not <3.36mm in thickness, all the IFC protected CFST columns were found satisfying fire resistance rating of 180 min, and after fire test the specimen deformation was still below beyond failure which indicated a higher fire resistance capacity than 180 min. At the end of each test the temperature of outer surface of the protected specimens was <350 °C, which was lower than the possible critical temperature to determine CFST column failure (600~700 °C or even higher) shown in fig (4). Meanwhile, the steel tubes just started high-temperature softening at the end of the tests because critical temperature for steel softening onset is normally around 300 °C. All the IFC materials performed well during the tests, the coatings remained integrated and well attached to the columns until the end of the tests. During the tests, global and local deformation of the protected CFST columns was not observed and the core concrete was intact without being crushed.

Figure (4) Test of IFC protected specimen before and after testing

J.Y. Richard Liew [20] studied structural behavior of CFST columns using UHSC and HSS, experimentally and analytically on their fire resistance and he observed that within the practical range of load level (i.e., load level ≤ 0.65), the CFST columns using UHSC have better fire resistance than the ones using NSC or HSC, provided that 0.1% polypropylene fiber in volume is added and venting holes are provided to prevent explosive spalling. The fire performance of CFST columns using HSS is inferior to those using NSS due to the faster deterioration of the mechanical properties of HSS.

Umesh Sharma [21] did the tests where the columns were loaded axially under the concentric and eccentric load, and subjected to the standard ISO 834 fire in a furnace. The proposed design equations presented in this paper have been developed and validated against 238 (121 square, 104 circular and 13 rectangular) Standard Fire test results undertaken worldwide over the past 36 years. The proposed procedure has been shown to be conservative for CFST columns filled with either plain, steel fibre or bar reinforced concrete. Following a sensitivity analysis, a new member section constant "αb" value has been proposed for columns having different concrete infill type to calculate the buckling member factor of the column in fire. The proposed design procedure has shown to be more accurate than the current AS/NZS 2327 method. Limited experimental data was found in the literature for rectangular CFST columns in fire when compared to square and circular CFST columns, therefore, a further validation of the design procedure using laboratory experiment data for rectangular CFST columns will be pragmatic.

4. DISCUSSION

As can be seen from the experimental results of CFST columns mentioned above, the following conclusions can be drawn:

Load ratio, slenderness ratio, cross-sectional dimension, section type, fire protection coating and fire exposed sides had significant influence on fire resistance of CFST columns. Load eccentricity, addition of reinforcing bars, and concrete type had moderate influence on fire resistance of CFST columns. Thickness of steel tube and steel strength had slightly influence on fire resistance of CFST columns. The fire performance behavior of high strength CFST columns was significantly different from that of normal strength CFST columns. The use of carbonate aggregate in concrete-filling provided about 10% higher fire resistance than siliceous aggregate.

Concrete-filled double skin tubular columns could have better fire endurance than unfilled and CFST columns. It is a well-known fact that size has an effect on nominal strength of specimens made with quasi-brittle materials such as concrete, rock, ice, ceramic, and composite materials. In compressive and flexural failures of quasi-brittle materials, the size effect is quite apparent. The phenomenon of normal strength depends on specimen size, is called the size effect, such as the normal compressive strength of concrete decreases as the specimen size increases. However, researchers were rare paid attention to size effect of fire performance of CFST columns. Compared with the ambient conditions, the influence of temperature distribution of specimens is the major difficulty to solve the problem of size effect of fire performance of CFST columns.

5. CONCLUSIONS

This paper presents a review on the behaviour of CFST columns when on fire. Previous studies show that unprotected steel tube columns have increased fire resistance when filled with normal or high strength concrete. There are some gaps that need to be filled up concerning the fire resistance of CFST columns using light weight foamed concrete as infill material without reinforcement, considering its advantage of low thermal conductivity and light-weight over normal, high strength concrete. The behaviour of a CFST column filled with light weight foamed concrete is not known, thus it is necessary to study its behaviour as it might provide another alternative arrangement of the CFST column design looking at safety and economic aspects. Fire resistance design studies are required due to the several restrictions in the design guide available in the literature. Due to the uniqueness of standard fire tests, there is the need for more studies on standard fire tests of CFST column filled with light weight foamed concrete which is not covered in the current design guide (NRCC and Eurocode).

The performance-based design approach using ABAQUS software can be used for modelling thermal and mechanical responses of the CFST column to a more realistic fire exposure. As such, modelling the CFST column filled with light-weight foamed concrete using ABAQUS software can depict its behaviour when exposed to fire.

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