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Fire resistance of high strength concrete filled steel tubular columns under combined temperature and loading

*Chao-Wei Tang[1)]

[1)] *Department of Civil Engineering & Geomatics, Cheng Shiu University, No. 840, Chengcing Rd., Niaosong District, Kaohsiung City, Taiwan R.O.C.*
[1)] *tangcw@gcloud.csu.edu.tw*

ABSTRACT

This paper presents an investigation on the fire resistance of high strength concrete filled steel tubular columns (CFTCs) under combined temperature and loading. Two groups of full-size specimens were fabricated to consider the effect of type of concrete infilling (plain and reinforced) and the load level on the fire resistance of CFTCs. Prior to fire test, a constant compressive load was applied to the column specimens. Thermal load was then applied on the column specimens in form of ISO 834 standard fire curve in a large-scale laboratory furnace until the set experiment termination condition was reached. The results demonstrate that the higher the axial load level, the worse the fire resistance. Moreover, in the bar-reinforced concrete-filled steel tubular columns, the presence of rebars not only decreased the spread of cracks and the sudden loss of strength, but also contributed to the load-carrying capacity of the concrete core.

1. INTRODUCTION

The definition of high-strength concrete (HSC) varies on a geographical basis. According to the American Concrete Institute, HSCs are those that attain cylinder compressive strength of at least 41 MPa at 28 days (ACI 363R-92 1992). In general, HSC has increased modulus of elasticity, which increases stability and reduces deflection (Jagannath et al. 2016). Therefore, HSC has been recently becoming an increasingly popular building material for various applications. Especially, composite columns made of HSC filled steel hollow sections have the advantages of high bearing capacity, large stiffness, good seismic performance, and convenient installation (Liew and Xiong 2015). Moreover, steel reinforced concrete structures have several practical benefits. For instance, compared with bare steel or reinforced concrete columns, the use of concrete-filled box or tubular columns (CFBCs or CFTCs) may have as a relatively small sectional dimension and omission of formwork, which decreases labor and material costs (Han et al. 2005, Lavanya and Elangovan 2017, Zhou et al. 2017).

[1)] Professor

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In addition, the use of composite steel-concrete building elements also results in a high level of fire resistance without the need for fire protection (EN 1994-1-2 2005). Consequently, CFBCs or CFTCs have been applied more extensively in the construction of modern high-rise buildings, bridges, and plants throughout the world over the past few decades (Lie and Kodur 1996, Kodur 1999, Uy 2001, Kodur et al. 2004, EN 1994-1-2 2005, Kim et al. 2005, Kodur 2007, Ding and Wang 2008, Espinos et al. 2009, Hong and Varma 2009, Song et al 2010, Aslani et al 2015, Qu et al 2015, Khan et al 2016, Ekmekyapar 2016, Mago and Hicks 2016, Tao et al. 2016, Wan and Zha 2016, Chen et al. 2017, Tan and Nichols 2017, Tang and Chen 2017, Tang 2017).

Building fires typically reach temperatures of around 1000 °C, which can reduce the loadbearing capacity of structural elements and cause damage or collapse of the structure. Therefore, most building codes stipulate that the structural elements of a building have to satisfy appropriate fire safety requirements (ACI-318 2014, EN 1992-1-2 2004, Kodur 2014). Fire protection features on structural elements are usually measured in terms of fire resistance, which is the ability of a given structural element to perform its design function for a period of time in the event of a fire (Purkiss 2007). Overall, the design rules for the fire resistance of existing structural elements such as steel, concrete, masonry and wood are based entirely on the results and observations of standard fire tests. Traditionally, fire resistance has been evaluated by subjecting a structural element in a furnace for a specified duration (ASTM E119 2008). The resulting fire rating is expressed in time, usually in minutes. In other words, fire rating is used to indicate the time that a structural element can withstand the effects of a standard fire test before reaching the specified destruction criteria. According to the standard fire test results, the fire rating of structural elements is divided into: R30, R60, R90, R120, R180 and other categories.

According to Eurocode 4 (EN 1994-1-2 2005), the structural fire design of composite steel and concrete columns consist in three different levels of assessment, namely tabular data, simple calculation models, and general calculation models. The tabulated data method was based on observations resulted from experimental study and was easy to apply. But application of tabulated data is confined to individual structural members, considered as directly to fire over their full length. In addition, thermal action is taken in accordance with standard fire exposure. Moreover, the tabulated data method is valid for columns with a maximum length of 30 times the minimum external dimension of the cross-section chosen. On the other hand, it was for specific types of structural members. In other words, it was limited by the geometrical conditions imposed to the composite cross-section. For example, the tabular data for the fire design of composite columns made of concrete filled steel hollow sections subjected to axial compressive loading are given in Table 1 (EN 1994-1-2 2005). As can be seen in Table 1, the standard fire resistance is found as a function of the load level, $\eta_{fi,t}$, the cross-section size *b*, *h* or *d*, the reinforcement rate, i.e., the ratio between the cross-sectional area of reinforcement and the total area, $A_s/(A_c+A_s)$, and the distance between the reinforcements and internal surface of the steel tube, u_s. The load level for fire design at time t, $\eta_{fi,t}$, is given by:

$$\eta_{fi,t} = \frac{E_{fi,d,t}}{R_d} \quad (1)$$