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Behaviour of fire-exposed concrete-filled steel tubular beam columns repaired with CFRP wraps

Zhong Tao[a,*], Lin-Hai Han[b,c]

[a]College of Civil Engineering, Fuzhou University, Gongye Road 523, Fuzhou, Fujian Province, 350002, People's Republic of China
[b]Department of Civil Engineering, Tsinghua University, Beijing 100084, People's Republic of China
[c]Key Laboratory of Structural Engineering and Vibration of China Education Ministry, Tsinghua University, Beijing 100084, People's Republic of China

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Abstract

This paper presents the test results of fire-exposed concrete-filled steel tubular (CFST) beam columns repaired by unidirectional carbon fibre reinforced polymer (CFRP) composites. Both circular and square specimens were tested to investigate the repair effects of CFRP composites on them. The test results showed that the load-bearing capacity of the fire-exposed CFST beam columns was enhanced by the CFRP jackets to some extent, while the influence of CFRP repair on stiffness was not apparent. The strength enhancement from CFRP confinement decreased with the increasing of eccentricity or slenderness ratio. Ductility enhancement was also observed except those axially loaded shorter specimens with rupture of CFRP jackets at the mid-height, occurred near the peak loads. However, the strengths of all repaired specimens have not been fully restored due to the long exposure time of them in fire. From the test results, it is recommended that, in repairing severely fire-damaged CFST members, slender members or those members subjected to comparatively large bending moments, other appropriate repair measures should be taken.

Keywords: Concrete-filled steel tubes (CFST); Beam columns; Fire-exposed; FRP; Post-fire; Residual strength; Repair

1. Introduction

In recent years, the use of concrete-filled steel tubes (CFST) in different areas of construction is gaining popularity [1–3]. Concrete-filled steel tube is one type of composite construction and has many advantages in engineering practice. The steel tube provides confinement to the concrete core, and thus increases its strength and ductility. Meanwhile, the concrete reduces the possibility of local buckling of the steel wall. An additional merit is that no formwork is required for the concrete during construction.

It is well-known that fire is always one of the most serious potential risks to modern high-rise buildings. With the increasing use of concrete-filled steel tubes as structural members, there is a growing need to understand the effect of fire on them and to provide measures for post-fire repair of such kind of composite members [4]. In the past, many studies have been performed on the fire resistance of CFST columns [1,5], as well as their residual strengths after exposure to fire [6–8]. However, very limited research has been conducted so far concerning the repair of fire-damaged CFST members [9,10].

To cater for the potential needs, Han and Yang [11] proposed several possible solutions for the repair/strengthening of CFST members to restore/enhance their strength or stiffness. The repair solutions may include several section enlargement methods (Fig. 1(a)–(c)) or wrapping with fibre reinforced polymer (FRP) composites (Fig. 1(d)).

Fibre reinforced polymer is composed of fibres embedded in a resin matrix, and is characterised by high strength-to-weight ratio, high corrosion resistance and ease of installation. Over the past few decades, FRP material has gained its popularity as a jacketing material in retrofitting/repairing existing concrete structures or steel structures [12–16]. More recently, some research results

*Corresponding author. Tel.: +86 591 87892459; fax: +86 591 83737442.
E-mail address: taozhong@fzu.edu.cn (Z. Tao).

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Nomenclature

A_{sc}	cross-sectional area of CFST section
B	outer width of square steel tube
CFRP	carbon fibre reinforced polymer
CFST	concrete-filled steel tube
D	outer diameter of circular steel tube
DI	ductility index
e	load eccentricity
f_{cu}	characteristic cube strength of concrete
f_y	yield strength of steel
FRP	fibre reinforced polymer
i	radius of gyration of CFST ($=\sqrt{I_{sc}/A_{sc}}$)
I_{sc}	second moment of area for CFST cross-section
K_e	stiffness of composite column
L	length of specimen
N	axial load
n_{frp}	number of CFRP layers
N_{ue}	experimental ultimate strength of composite column
RSI	residual strength index
SEI	strength enhancement index
t	fire duration
t_s	wall thickness of steel tube
u_m	deflection at mid-height
Δ	axial shortening
ε	strain
λ	slenderness ratio ($=L/i$)

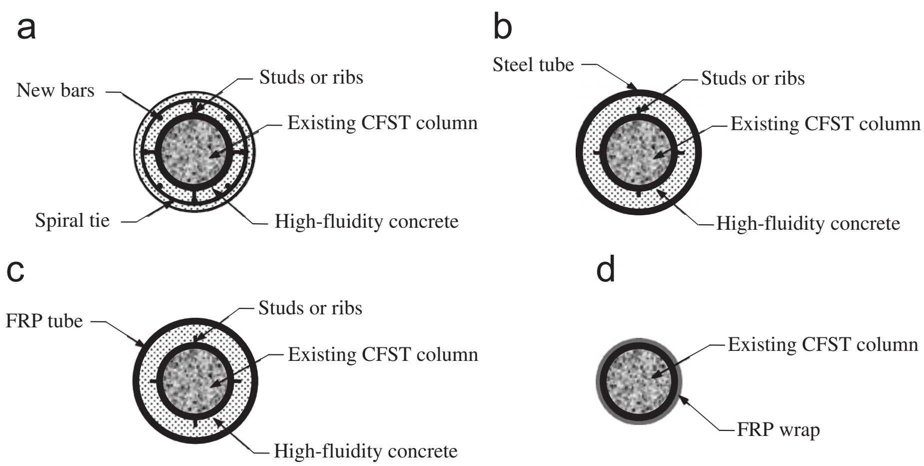

Fig. 1. Solutions for repair or strengthening of CFST members. (a) Section enlargement with reinforced concrete jacketing, (b) section enlargement with steel tube and sandwiched concrete jacketing, (c) section enlargement with FRP tube and sandwiched concrete jacketing, (d) wrapping with FRP composites.

have been reported on the strengthening of CFST stub columns, which have preliminarily demonstrated the effectiveness of the carbon fibre reinforced polymer (CFRP) wraps in increasing the axial loading capacity of CFST stub columns [9,17,18].

In the past, section enlargement method has been proved suitable to be used in rehabilitation of reinforced concrete columns [11]. It is expected that this method will also be effective in repairing fire-damaged CFST columns. However, it will result in a significant increase in the column cross-section and a comparatively long construction time. FRP jacketing is a more recent method and is particularly attractive in that it does not significantly increase the section size and is easy to install.

In order to evaluate the effectiveness of the above two repair methods and identify method gaps, the authors have been engaged in research studies on this topic recently. Test results of 25 CFST specimens, in which nine of them were fire damaged and then strengthened by wrapping the original columns by concrete and a thin walled steel tube, have been reported in [19]. These specimens were tested under a constant axial load and a cyclically increasing flexural load. The test results indicate that the strength and the stiffness of the strengthened columns can be restored over the previous level of the specimens.

As far as the wrapping FRP method is concerned, Tao et al. [10] have carried out preliminary tests on fire-exposed CFST stub columns and beams repaired with CFRP wraps. It demonstrated that FRP composites were effective in enhancing the load-carrying capacity of stub columns, while the strengthening effect for beams was quite limited if only unidirectional FRP was used to confine the beams. The research results reported in this paper are part of a wider study concerning the repair of fire-exposed CFST beam columns.

New test data concerning concrete-filled steel tubular beam columns, that have been exposed to and damaged by the standard ISO-834 fire and subsequently repaired are provided in this paper. Twenty-eight beam columns, including 14 circular specimens and 14 square ones were