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Experimental performance of concrete-encased CFST columns subjected to full-range fire including heating and cooling

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ABSTRACT

Concrete-encased CFST (concrete-filled steel tube) columns are gaining popularity in constructions especially in high-rise buildings and large-span structures. This type of composite column features an inner CFST component and an outer reinforced concrete component. Extensive literature is available on the structural performance of concrete-encased CFST columns at ambient temperature, however, the fire performance of this type of composite columns has seldom been addressed. To fill in this research gap, this paper thus experimentally studies the performance of concrete-encased CFST columns subjected to full-range fire including heating and cooling. A set of tests, including six fire resistance tests and four postfire tests, respectively, were conducted under the combined effect of load and fire. Test observations and results are presented, including fire resistance, postfire residual strength, failure modes, temperature versus time relationships and deformation versus time relationships. The fire performance of concrete-encased CFST columns is analysed and discussed based on these observations. It is found that due to the insulating effect of the outer reinforced concrete, concrete-encased CFST columns exhibits higher fire resistance in fire and higher postfire residual strength as compared with conventional CFST columns without concrete encasement. The simple calculation model of analysing the fire resistance of composite column in Eurocode 4 was extended and then employed to calculate the fire resistance as well as the postfire residual strength of concrete-encased CFST columns. The predictions are found to be conservative as compared with test data, and this simplified method are applicable to assess the fire resistance and postfire residual strength of concrete-encased CFST columns.

1. Introduction

Concrete-encased CFST (concrete filled steel tube) columns are a type of composite structure comprising an inner CFST component and an outer reinforced concrete (RC) component, as shown in Fig. 1. This type of composite columns is gaining popularity in constructions in China, especially in high-rise buildings and large-span structures. They were initially designed to achieve high seismic performance by (1) using concrete of higher strength classes inside the tube than the outside, and (2) casting the inner concrete first and employing the inner CFST component to sustain the construction loads afterwards. The inner CFST component can thus attain a higher load level than the outer RC component. The outer RC component with lower load level has more capacity to develop compressive stress when the member is subjected to seismic actions. It allows the column to fail in such a way that the longitudinal rebars yield in the tensile zone of the cross-section first and then the concrete in the compressive zone is crushed sequentially. The bending resistance can thus be increased and the seismic-induced failure can be delayed. This design concept of load share distribution is beneficial to the seismic performance of concrete-encased CFST member, and a large amount of research work is available [1–6] on their seismic performance.

Concrete-encased CFST columns are also characterized by high strength, high stiffness and superior ductility. The confinement effect exists not only between the steel tube and the inner concrete, but also between the outer RC component and the steel tube. Therefore, the steel tube's resistance to both inwards and outwards local buckling can be enhanced. A few studies are available on the static performance of concrete-encased CFST column at ambient temperature. For example, Han and An [7] studied the performance of concrete-encased CFST columns under combined compression and bending. A finite element analysis (FEA) model was developed and validated against the test data. A simplified model was also proposed to predict the sectional capacity of concrete-encased CFST columns under combined compression and bending. An et al. [8] experimentally and numerically investigated the flexural performance of concrete-encased CFST columns, and the

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Notation

B_c	width of the concrete-encased CFST cross-section	N_{urP}	predicted value of the postfire residual strength of concrete-encased CFST column
D	outer diameter of circular steel hollow section or diameter of reinforcing bars	n	load ratio, $=N_f/N_u$
D_c	depth of the concrete-encased CFST cross-section	R	Coefficient of postfire residual strength, $=N_{ur}/N_u$ or $=N_{urP}/N_u$
f_u	ultimate strength of steel	t	time
f_y	yield strength of steel	t_h	duration of fire exposure
H	height of column	t_o	heating time ratio, $=t_h/t_R$
M	bending moment	t_R	measured value of fire resistance
N	axial load	t_{RP}	predicted value of fire resistance
N_f	load applied on the column in the fire situation and during cooling down	t_s	wall thickness of steel hollow section
N_u	ultimate strength of concrete-encased CFST column at ambient temperature	Δ_c	axial displacement
N_{ur}	measured value of the postfire residual strength of concrete-encased CFST column	θ	temperature, in °C
		θ_{cr}	critical temperature, in °C
		θ_{max}	maximum temperature attained in the fire situation including heating and cooling, in °C
		λ	slenderness ratio

simplified formulas for predicting the bending resistance were derived. Han and An [9] investigated the performance of concrete-encased CFST stub columns under axial compression and proposed simplified formulas for calculating the ultimate strength. Han et al. [10] studied the behaviour of concrete-encased CFST members under axial tension and proposed a simplified model to predicted the members' tensile strength.

Besides the performance at ambient temperature, concrete-encased CFST columns are also expected to display enhanced fire performance due to the insulating effect of the outer RC component. The temperature rise of the inner CFST component would lag behind the outer RC component, allowing the occurrence of the redistribution of load share in the fire situation. This insulating effect could also reduce the maximum temperature attained by the inner CFST component during full-range fire including heating and cooling, which is favourable to the member's retaining its capacity after fire exposure. To date, the fire performance of concrete-encased CFST column has seldom been investigated. However, the research on the fire performance of other composite members comprising steel and concrete has been conducted. A large amount of work is available on the performance of conventional CFST columns in fire, such as the extensive test programs in Europe in the 1980s [11–13], the National Research Council of Canada program in the 1990s [14–19], Wang [20], Han et al. [21], Tan and Tang [22], Rodrigues and Laim [23], and Espinos et al. [24], etc. Fire performance of CFST columns with high strength concrete infilled [25,26] and subjected to large eccentricities [27] are also available. Recently, the fire performance of a novel type of composite column, i.e., CFST with solid inner steel core, was also investigated [28–31]. This type of composite column can benefit from the redistributions of the load share in the fire situation. Moreover, the fire behaviour of seismically predamaged concrete filled double skin tube column was also investigated experimentally and numerically [32,33].

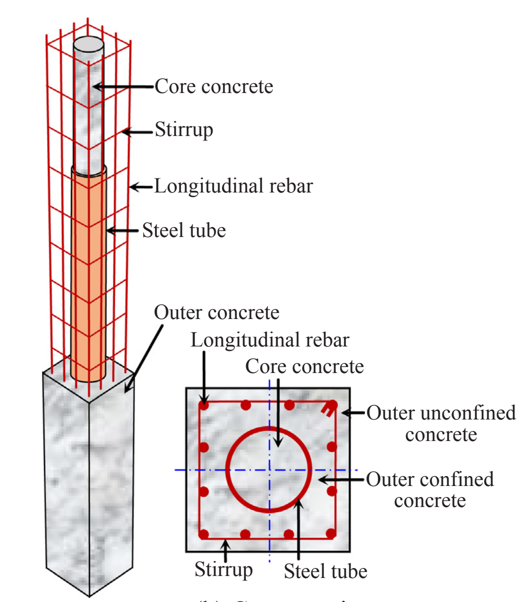

Fig. 1. Schematic view of a typical concrete-encased CFST column.

Buildings may not experience major failure after a real fire, and the structures can be reused safely after proper assessment and repair. Hence, it is also essential to investigate the postfire performance of structural members. A few works are available on postfire performance of structural members. Lin et al. [34] investigated the postfire behaviour of RC columns. Lin et al. [35] studied the strength and stiffness of RC columns repaired after fire damage. Young and Ellobody [36] and Han et al. [37] studied the behaviour of steel reinforced concrete (SRC) column in and after fire, respectively. Yang et al. [38] studied the postfire performance of CFST columns subjected to fire including heating and cooling. Rush et al. [39] presented a set of postfire residual compression tests on CFST column and predicted the residual capacity of CFST column after fire.

Set against this background, this paper investigates the performance of concrete-encased CFST columns subjected to the complete temperature-load-time path as shown in Fig. 2. This path includes four phases, i.e., a loading phase at ambient temperature (AA′), a standard fire exposure phase (A′B′), a cooling phase with load applied (B′C′D′) and a postfire loading phase (D′E′). The following work has been

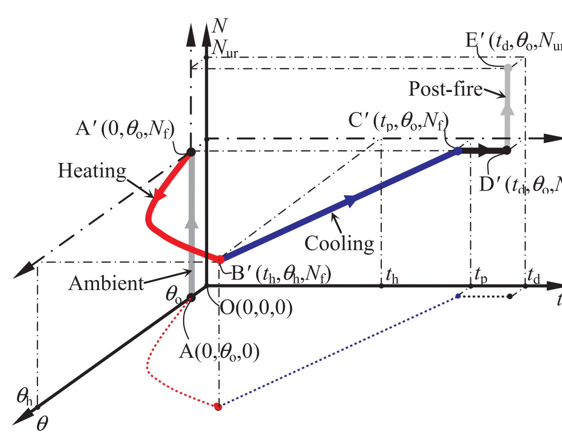

Fig. 2. Complete temperature (θ)-load (N)-time (t) path.