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Analytical behaviour of RC beam to CFST column frames subjected to fire

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ABSTRACT

The present study is a theoretical investigation on the fire performance of concrete filled steel tubular (CFST) column and reinforced concrete (RC) beam frames. The planar composite frame consists of two CFST columns and a RC beam with slab. A finite element analysis (FEA) model was developed and verified against test results of the same composite frames presented in the companion paper. A comparison of results calculated using this model shows generally good agreement with test results. The FEA model is then used to investigate the behaviour of similar framed structures in fire. Stresses and strains are analyzed as well as structural deformations and internal forces to identify the failure mechanism of the frames. The influence of important parameters on the load bearing mechanism of the composite framed structures investigated specifically and suggestions are made regarding calculation of the fire resistance of the frame.

1. Introduction

A series of fire tests were performed on a frame structure in Cardington, the UK in the 1990s. During the tests, significant differences were observed between the fire performance of structural members within the frame and isolated individual components that were traditionally tested in the ISO-834 Standard Fire (Bailey [1]; Wang [2]; Gillie et al. [3]). In recent years, more and more attention have been paid to the fire resistance or mechanical behaviour of structural members in fire, and the subjects of fire safety research have been shifted to structural frames or still structural members but with the restrained boundary conditions or existence of the rest frame appropriately considered (Elsawaf et al. [4]; Elsawaf and Wang [5]).

Composite members such as CFST columns are more complicated than the steel members used in the Cardington frame and research on the behaviour of structures consisted of composite members have only been started in recent years. The behaviour of a member in a frame can be treated as an individual member with finite amounts of displacement and rotation restraint at both ends. Therefore, understanding to the behaviour of these structural members still highly relies on the understanding to the load bearing mechanism of individual isolated members. This is a sister paper to a paper previously published (Han et al. [6]), which was mainly concerned with experimental studies of composite frames and has given a simple review to the tests performed to composite members and composite frames. Fig. 1(a) shows the frames before the casting of concrete, Fig. 1(b) shows the details of the composite frame. In this paper, an analytical analysis will be performed to the behaviour of composite frames using CFST columns and reinforced concrete (RC) beams in fire. Before that, analytical research to CFST columns and RC beams will be reviewed.

Lie and Stringer [7] predicted the cross-sectional temperature and axial contraction of circular steel columns filled with plain concrete using a self-developed annular element. Han et al. [8,9] studied mechanical behaviour of concrete-filled steel tubular columns with or without fire protection subjected to fire exposure. Simplified numerical model was developed and parametric analyses were carried out with the developed model. Formulas were proposed to calculate the fire resistance or the required fire protection thickness for CFST columns. Kodur [10] developed a simplified method for calculating the fire resistance of concrete filled steel HSS columns.

Ding and Wang [11] performed a research to study the influence of air gap, slip between steel tube and core concrete, tensile strength of concrete and initial imperfections on the fire resistance of concrete-filled steel tubular columns, and before that the FEA model was validated against experimental results of tests on 34 CFST columns. Chung et al. [12] compared the effect of material models on the fire resistance of CFST columns by employing several material models for steel and concrete at elevated temperatures.

Al-Khaleefi et al. [13] employed an artificial neural network method in predicting the fire resistance of CFST columns considering different factors due to structure, material and loading

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Nomenclature

a	fire protection thickness of CFST column
b	width of RC beam
D	column cross-sectional dimension
H	height of column
h	section depth of RC beam, including the thickness of RC slab
k	beam-to-column linear rotation restraint ratio, given by $k=\frac{(EI)_{beam}/L}{(EI)_{column}/H}$, where $(EI)_{beam}$ and $(EI)_{column}$ are the flexural stiffness of beam and column, respectively
L	span of RC beam
m	load level in beam (=P_F/P_u)
M_b	sagging moment in the beam mid-span or hogging moment in the beam joint
M_c	moment in the CFST column
n	level of axial load in column (=N_F/N_u)
N_F	axial load applied on the column
N_b	axial force in the RC beam
P_F	lateral load applied on the beam
q_b	distributed load applied on the RC beam and slab
t	fire duration time
t_R	fire resistance time of individual CFST columns
t_{RF}	fire resistance time of structural frames
t_s	wall thickness of steel tube
T	temperature (°C)
V_b	shear force in the RC beam
δ_b	deflection in beam mid-span
Δ_c	axial contraction for columns
Δ_h	horizontal displacement
σ_c	stress of concrete
σ_s	stress of steel
ε_c	strain of concrete
ε_s	strain of steel

conditions. Hozjan et al. [14] extended artificial neural network in fire analysis of steel frames. However, the neural network needed to be trained by a large amount of experimental data to produce a reliable result.

Most of the CFST columns mentioned earlier were studied with idealized boundary conditions, and for which, a lot of knowledge has been established. It is then the intention of this paper to move the study on CFST columns toward the fire performance of RC beam to CFST column frames, which considers the interaction between connecting structural members and is more representative of real buildings. Here, a RC beam is chosen to work together with CFST columns, as shown in Fig. 1, which is a typical kind of construction widely used in China.

Experimental and numerical research work has been carried on the fire performance of RC/composite slabs (Bailey [15]; Huang et al. [16,17]) and RC beams (Bratina et al. [18]), and an alternative simplified procedure for the analysis of three-dimensional frames in fire was presented by Junior and Creus [19], which can be used to analyse 2D and 3D frames at elevated temperatures. Fire performance analysis of steel frames (Skowroński [20]; Bailey [21]) or RC structures (Kodur et al. [22]) were already carried out, but very little research on CFST column to RC beam framed structures were reported till now.

In the companion paper (Han et al. [6]), six tests on framed specimens consisting two square CFST columns and a RC beam with slab exposed to ISO-834 standard fire were reported. Fig. 1

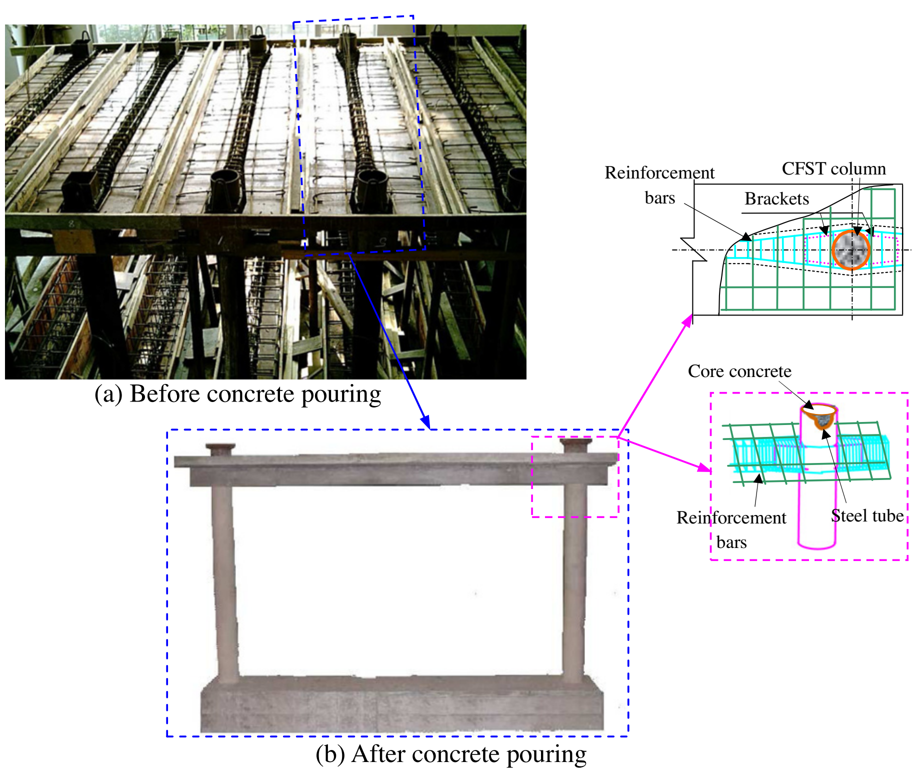

Fig. 1. Typical CFST column–RC beam frame.