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Behaviour of continuous concrete filled steel tubular columns loaded concentrically in fire

Kingsley U. Ukanwa[a], Umesh Sharma[b], Stephen J. Hicks[c], Anthony Abu[d], James B.P. Lim[a], G. Charles Clifton[a,*]

[a] Department of Civil and Environmental Engineering, The University of Auckland, Auckland, New Zealand
[b] Department of Civil Engineering, India Institute of Technology, Roorkee, India
[c] New Zealand Heavy Engineering Research Association, HERA House, Auckland, New Zealand
[d] Department of Civil and Natural Resources Engineering, University of Canterbury, Christchurch, New Zealand

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ABSTRACT

Design recommendations for concrete filled steel tubular (CFST) columns in fire are based on the results of experimental standard fire testing of CFST members where the same temperature is applied to the column over the full column height. However, this is not representative of a CFST column in a typical building, which is continuous between floors and which, in fire, is subjected to severe fire conditions on one floor at a time while the floors above and below remain cooler. In the experimental tests described in this paper, the columns are of 3.2 m height with the fire applied only to the central 2 m. Significant differences are observed between these tests and those previously conducted due to the partial length heating. In total, ten tests are conducted; the tests cover three different types of infill: plain concrete; bar reinforced concrete; and steel fibre reinforced concrete. End restraint conditions of fixed-fixed (F-F) and pinned-fixed (P-F) are considered; the axial load levels are between 0.33 to 0.38 of the squash load. The longitudinal elongation of the steel tube was less than 3 mm. Using the experimentally measured structural fire resistance (R), the axial capacity in fire was calculated in accordance with the codes of practice and are Compared with the experimentally tested structural fire resistance, showing that in some instances current design practice can be un-conservative.

1. Introduction

Unprotected concrete filled steel tubes (CFST) (i.e. with no insulation material applied to the outside of the steel tube) can have an inherent fire resistance, due to concrete preventing inward buckling of the steel tube and hence increasing its local and global buckling resistance and the steel tube partially or totally confining the concrete, to give the column a higher compressive strength. In addition, the steel tube acts as a partial radiation shield to the concrete [1]. In the literature, the performance of CFST under ISO 834 [2] Standard Fire conditions has been considered by, amongst others, Romero et al. [3], Kodur and Latour [4] and Lie and Irwin [5], and has covered three types of in-fill; plain concrete, steel fibre reinforced concrete and rebar reinforced concrete. Finite element analyses studies have also been reported [6–9] which cover CFST columns filled with normal strength and high strength concrete loaded axially with high utilization factor in fire. The finite element analysis studies, however, have not covered continuous columns in fire.

In all previously reported experimental tests and finite element analyses, the entire column height is heated. In New Zealand, these columns are required to be continuous over their full length for seismic design requirements. The full length heating of the column is not representative of a fire cell in a continuous column construction where the fire is on one floor and the floors above and below remain cooler. This paper considers the behaviour of a continuous column heated over part of its length at one time.

The experimental tests reported herein consider the issue of partially heated length in a continuous column and different concrete infills having measured compressive strength ranging from 80 MPa to 95 MPa. In total ten tests were conducted, with temperature only applied to 2 m of a 3.2 m high column (see Fig. 1); all tests were conducted on square hollow steel sections having nominal cross-sections dimensions of 200 mm × 200 mm × 6 mm and 220 mm × 220 mm × 6 mm; the yield strengths of the sections tested ranged from 461 MPa to 569 MPa. The tests cover three different types of infill: plain concrete; bar reinforced concrete; and steel fibre

* Corresponding author.
E-mail address: c.clifton@auckland.ac.nz (G.C. Clifton).

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Nomenclature

$A_{s,T}$	cross-sectional area of steel profile at the temperature °c
$A_{c,T}$	cross-sectional area of concrete at the temperature °c
$A_{r,T}$	cross-sectional area of reinforcement at the temperature °c
Am/V	section factor
$E_{s,T}$	modulus of elasticity of steel
$E_{c,T}$	tangent modulus of concrete at the temperature °c
$E_{fi,Exp}$	design effect of actions in fire situation for laboratory experiment
$E_{fi,Rd}$	design effect of actions in fire situation for design code
$E_{c,sec,T}$	secant modulus of concrete at the temperature °c
$E_{r,T}$	modulus of elasticity of reinforcement at the temperature °c
$(EI)_{fi}$	effective flexural stiffness in fire situation
F-F	Fixed - Fixed
F-P	Fixed - Pinned
f_c	compressive cylinder strength of concrete at room temperature
f_r	yield strength of reinforcement at room temperature
f_s	yield strength of structural steel at room temperature
$I_{c,T}$	second moment of area of concrete at the temperature °c
$I_{s,T}$	second moment of area of steel profile at the temperature °c
$I_{r,T}$	second moment of area of reinforcement at the temperature °c
k	effective length factor
$L_{e,T}$	buckling length of column in fire situation
$N_{c,fi,Rd}$	design cross-sectional plastic resistance to axial compression in fire
$N_{b,fi,Rd.,t}$	design axial buckling load of column in fire situation
R	structural fire resistance
t	steel tube thickness
α_c	member slenderness reduction factor
T	temperature
T_c	temperature of concrete
T_s	temperature of steel
T_r	temperature of reinforcement
λ_r	relative slenderness of column at room temperature
$\lambda_{,T}$	relative slenderness of column in fire situation
η_{fi}	design load level in fire condition
δ	steel contribution ratio

reinforced concrete [10–13]. End restraint conditions of fixed-fixed (F-F) and pinned-fixed (P-F) were considered. Compressive load levels η_{fi} of 0.33 and 0.38 were applied, with the loads determined in accordance with the provisions in DR AS/NZS 2327 [14], which are based on the recommendations of Espinos et al. [15].

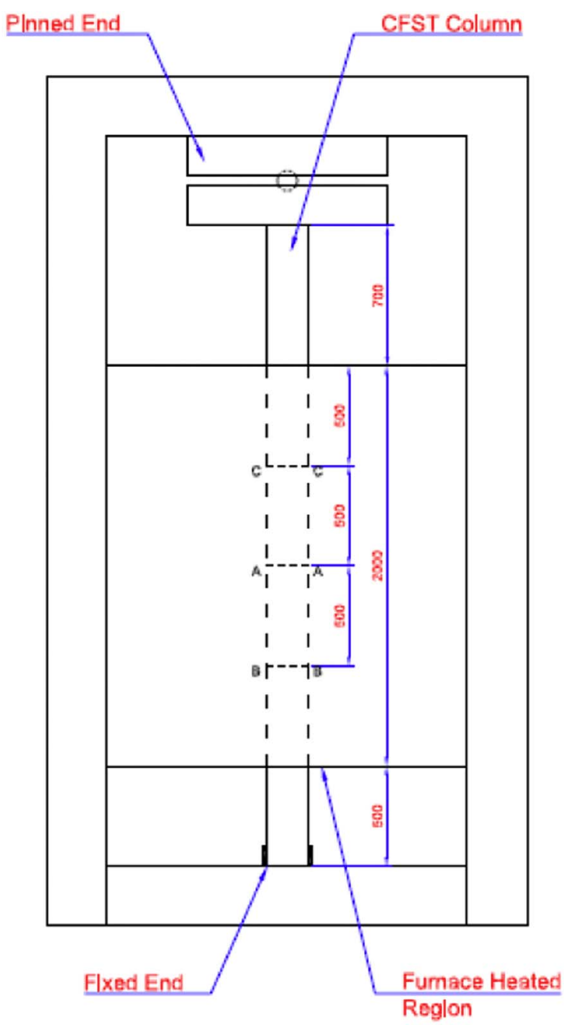

Fig. 1. Fire furnace schematic setup for fixed-pin.

Using the experimentally measured structural fire resistance (R), the column axial capacity in fire was calculated in accordance with both DR AS/NZS 2327 and EN 1994-1-2. It was found that these code provisions can be un-conservative in some instances and that they exhibit a wide variation compared with the experimental results and modifications to the effective length recommendations as applied to continuous columns are required.

2. Experimental investigation

2.1. General

The fire tests were conducted in a 2 m height × 1.5 m length × 1.5 m width furnace in IIT Roorkee, India, in accordance with EN 1364-1: 2012 [16] and with the furnace temperature controlled to match the ISO 834 [2] time-temperature curve. Fig. 2 shows the typical average furnace temperature in comparison to the ISO 834 fire curve for a typical test. The axial load was applied for 30 min before each fire test and was maintained at the applied level until the appropriate designated failure criterion from [16] was met.

2.2. Test specimens

Table 1 summarises the test specimens, material properties and load

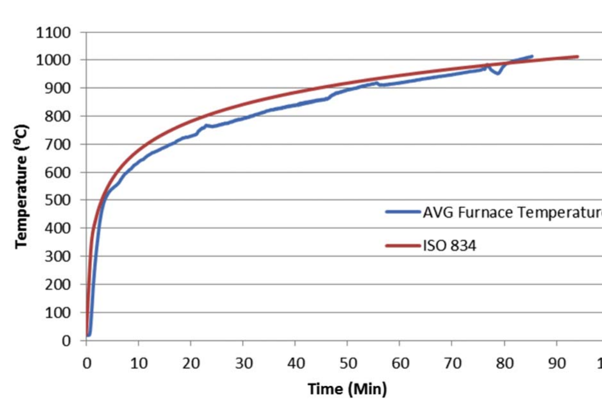

Fig. 2. Measured furnace temperature (ISO 834 shown for comparison).