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Experimental analysis of built-up closed cold-formed steel columns with restrained thermal elongation under fire conditions

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ABSTRACT

An experimental research on the fire behaviour of compressed cold-formed steel columns with closed built-up cross-sections and restrained thermal elongation is presented. Several parameters were assessed, including the influence of loading level, boundary conditions, restraint to thermal elongation imposed by the surrounding structure and cross-sectional shape. The investigation suggests that an increase in the non-dimensional axial restraint ratio and column load levels lead to a decrease in critical temperatures. Furthermore, the 350 °C critical temperature limit predicted in the EN 1993-1-3:2005 may be too simplistic and conservative for fire design of this type of columns.

1. Introduction

Cold-formed steel (CFS) built-up cross-sections are commonly used in the building construction industry. Nowadays, several cross-sections can be built using standard single sections (C, U, Σ, etc.) available, including open built-up and closed built-up cross-sections. Built-up cross-sections have several advantages over single sections. A built-up cross-section can span more distance, have a higher load bearing capacity and higher torsional stiffness [1]. Moreover, the use of built-up cross-sections can be a major economic advantage since the whole manufacture process remains the same [2].

Usually, these cross-sections are built using self-drilling screws or seam welding [3–5]. Some research concerning the ultimate load-carrying capacity of built-up closed CFS columns has been conducted at ambient temperature [1,4–7]. However, design methodologies presented so far in current design codes are still poor, especially for columns with closed built-up cross-sections subjected to fire. Traditionally, two design methods are used: The Effective Width Method (EWM) used worldwide and the Direct Strength Method (DSM) [8] used in North America, Australia/New Zealand [9,10]. The 2007 AISI Specification [9] states that built-up members should be designed considering a modified slenderness ratio $(KL/r)_m$ if the buckling mode involves relative deformations that produce shear forces in the connections between individual shapes.

$$\left(\frac{KL}{r}\right)_m = \sqrt{\left(\frac{KL}{r}\right)_0^2 + \left(\frac{a}{r_i}\right)^2} \quad (1)$$

where $(KL/r)_m$ is the overall slenderness ratio of the entire cross-section about the built-up cross-section member longitudinal axis, a is the intermediate fastener or spot welding spacing and r_i is the minimum radius of gyration of a full unreduced cross-sectional area of an individual shape in a built-up member. The EN 1993-1-3:2004 [11] only dictates that the buckling resistance of a closed built-up cross-section should be determined using the buckling curve b associated with the basic yield strength f_{yb}, and buckling curve c associated with the average yield strength f_{ya}, provided that $A_{eff}=A_g$. Regarding fire design, the methods in EN 1993-1-2:2005 [12] for hot-rolled steel members are also applicable to CFS members with class 4 cross-sections, albeit limiting the critical temperature to 350 °C.

No specialized literature has been found on the behaviour of built-up box cross-sections subjected to fire. The investigation on built-up closed cold-formed steel columns under fire conditions is still very scarce. In case of fire, it is very likely that a column in a real building will be subjected to thermal elongation. Since the column is thermally restrained by the surrounding structure, additional compressive forces (restraining forces) will be generated. This may lead to premature column failure and has already been

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Nomenclature

CFS	cold-formed steel
CV	coefficient of variation
d	lateral deformation
d_a	axial displacement
H	height of the column
I_c	moment of inertia of the column around the minor axis
$K_{a,s}$	axial stiffness of the surrounding structure
$K_{r,\ si}$	rotational stiffness of the surrounding structure in the direction *i*
$K_{a,c}$	axial stiffness of the column
$K_{r,\ ci}$	rotational stiffness of the column in the direction *i*
K_i	level of restraint of the surrounding structure (axial and axial associated to the rotational restraint)
LL	load level
$N_{b,Rd}$	design buckling resistance of a compression member
N_{cr}	elastic critical force for the relevant buckling mode
$N_{c,Rd}$	design cross-sectional resistance of the section to uniform compression force
P	axial restraining force generated in the column
P_{max}	maximum axial force generated in the column
P_0	initial applied load on the column
R. F.i	restraining frame number i
T	furnace mean temperature
T.i	thermocouple i
t_{cr}	critical time
t_n	nominal thickness of the cross-section
t_{peak}	time at which the maximum restraining forces in the column are reached
α_k	non-dimensional axial restraint ratio
α_L	non-dimensional level of applied load
ρ_i	non-dimensional rotational restraint ratio in direction i
$\bar{\theta}_C$	column mean temperature
θ_{cr}	critical temperature
θ_{cr}^{max}	critical temperature of the section with the highest temperature recorded
θ_{peak}^{max}	temperature of the section with the highest temperature recorded when the maximum restraining forces are reached
θ_{peak}	column temperature when the maximum restraining forces are reached
$\bar{\theta}_s$	cross-section mean temperature
$\bar{\lambda}$	non-dimensional slenderness
μ	mean value
σ	standard deviation

studied for hot-rolled steel, concrete and composite steel and concrete columns [13–15]. Due to the increasing usage of CFS columns, a thorough study of the effect of restraint to thermal elongation in CFS columns is clearly needed.

This paper presents the results of an experimental investigation on the behaviour of built-up cross-section CFS columns subjected to fire with restrained thermal elongation. The experimental tests were carried out at the University of Coimbra, Portugal.

The research aimed to investigate the fire behaviour of CFS columns as a part of a real building frame. Several parameters that may influence the overall behaviour of CFS columns in case of fire were tested, including: cross-sectional shape, level of restraint to thermal elongation, level of initial applied load and boundary conditions. Furthermore, the experimental investigation intended to gather relevant information for future numerical studies.

2. Experimental tests

2.1. Test set-up and procedure

This section describes the designed and built experimental test set-up [17]. Fig. 1a)–c) show schematic and global views of the test set-up. The figure illustrates a two-dimensional reaction steel

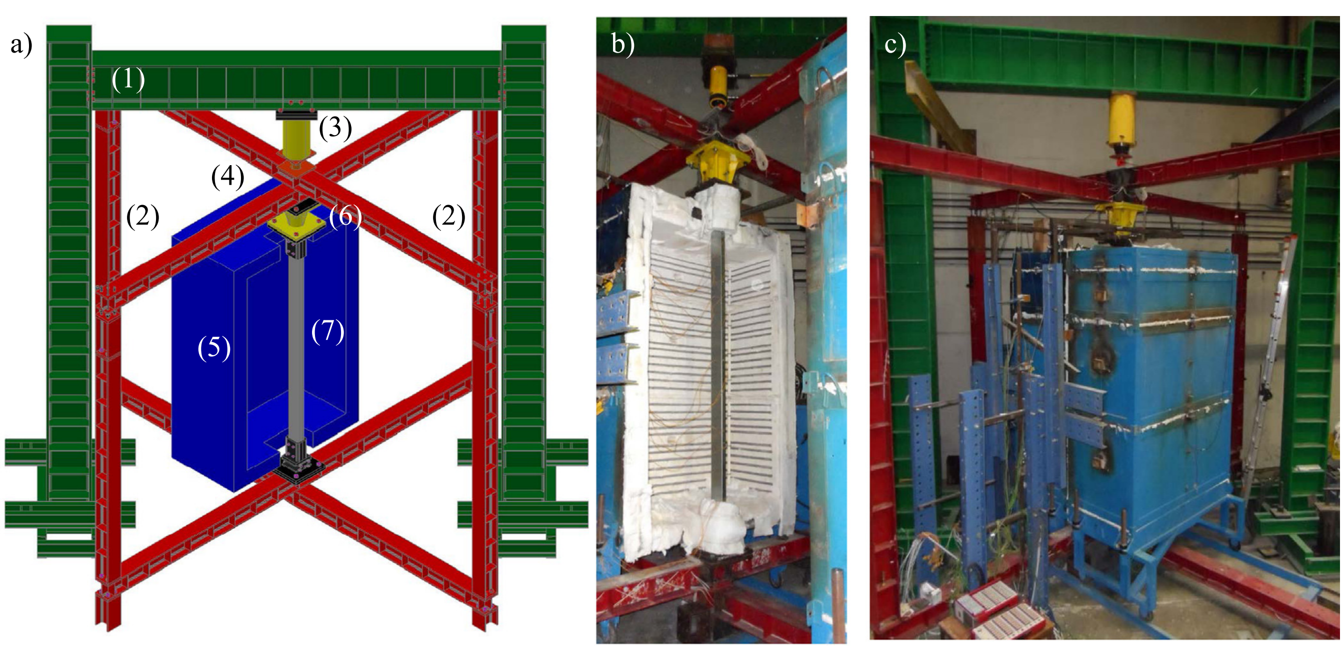

Fig. 1. a) Schematic view of the experimental test set-up. b) and c) Global views.