Influence of Brick Walls on the Temperature Distribution in Steel Columns in Fire

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This paper reports on a study of steel columns embedded in walls in fire. Several fire resistance tests were carried out at the Laboratory of Testing Materials and Structures of the University of Coimbra, in Portugal. The temperatures registered in several points of the experimental models are compared with those obtained in numerical simulations carried out with the SUPERTEMPCALC finite element program.

Keywords: Fire, walls, steel, columns, resistance, numerical simulation, Eurocodes.

1 Introduction

The fire resistance of a steel column is strongly influenced by the conditions in which it is inserted in the building. Apart form other parameters, the contact of the column with the walls of the building has a great influence on its behaviour in fire. The walls, on one hand, have a favourable influence on the fire resistance of the steel columns, because they protect a large part of its lateral surface from heating. However, on the other hand, they will have an unfavourable influence because they lead to differential heating of the cross-section. The design methods considered in Eurocode 3 part 1.2 do not take into account this fact, and fire resistance is determined as if the heating were uniform [1].

This paper presents the results of fire resistance tests in steel columns embedded on walls, carried out at the Laboratory of Testing Materials and Structures of the University of Coimbra. The evolution of temperatures registered in the experimental models is compared with the results obtained in numerical simulations performed with the SUPERTEMPCALC FEM program (STC), developed by Y. Anderberg of Fire Safety Design, Lund, Sweden [2]. SUPERTEMPCALC is a thermal finite element program that solves two-dimensional, non-linear, transient, heat transfer differential equations, incorporating thermal properties which vary with temperature. This program allows the use of rectangular or triangular finite elements, in cylindrical or rectangular co-ordinates. Heat transfer by convection and radiation at the boundaries can be modelled as a function of time.

2 Experimental program

The aim of this study was to analyse the thermal behaviour of steel columns embedded on walls. Fire resistance tests were carried out with two different column cross-sections, two orientations of the inertia axis in relation to the fire and two thicknesses of the building walls [3].

The columns had cross-sections of HEA160 and HEA200, steel class S355 and the walls of different thicknesses and were made of bricks (Fig. 3). The bricks were laid using ordinary cement mortar.

The columns in the test were placed at the center of a 3D restraining frame (Fig. 2a). This frame was composed of HEB200 columns 3 m in height and HEB200 beams with a 6 m span, steel class S355. Two brick walls were then built, one on each side of the column (Fig. 2b). This restraining frame was later used to perform fire resistance tests on columns with restrained thermal elongation, but in the tests presented in this paper the columns were not thermally restrained.

The specimens were instrumented with Type K thermocouples (cromo-alumel) in various positions of the cross-section of the columns and on the walls (Fig.1).

The thermal action was applied only on one side of the element, in such a way as to permit an analysis of the thermal gradient produced through the wall and across the cross section of the column. The evolution of temperatures in the furnace followed the ISO 834 standard fire curve. The temperatures inside the furnace were measured by Type K shielded probe thermocouples in the first four tests (cases 1 to 4 in Fig. 3) and were later exchanged for plate thermometers in the last four tests (cases 5 to 8 in Fig. 3). This change was due to the fact that a small delay in the heating of the furnace was observed in the first tests, and so the decision was taken to change the thermocouples that controlled the furnace.

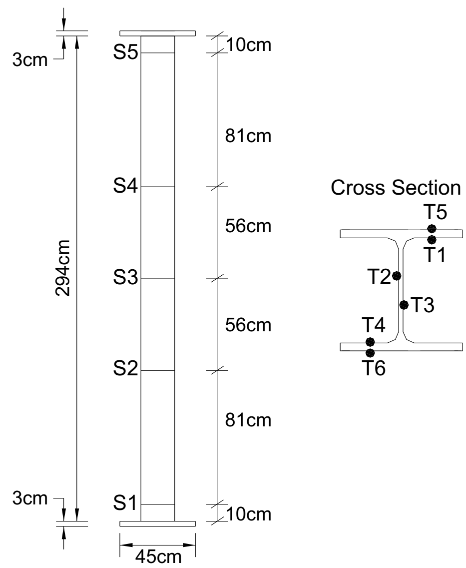


Fig. 1: Specimen and position of thermocouples

a) b) c)

Fig. 2: a) Construction of the test model, b) Column embedded in the wall, c) Lateral view of the experimental system

3 Numerical modelling

The computational modelling was performed using the computer code SUPERTEMPCALC (STC) – Temperature Calculation and Design v.5, developed by Y. Anderberg [2] for two-dimensional thermal analysis of any type of cross-sections exposed to heating.

The thermal properties of the materials adopted in this work for numerical analysis were those presented in Eurocode 3 [1] for steel, and in Eurocode 2 [4] for concrete parts 1.2. For the mortar covering the bricks, the properties for concrete recommended by Eurocode 2 part 1.2 were adopted.

The thermal properties adopted for the masonry were the same as the values adopted in the Ozone computer program, developed at the University of Liège, i.e.,
thermal conductivity = 0.7 W/m°C,
specific heat = 840 J/kg°C,

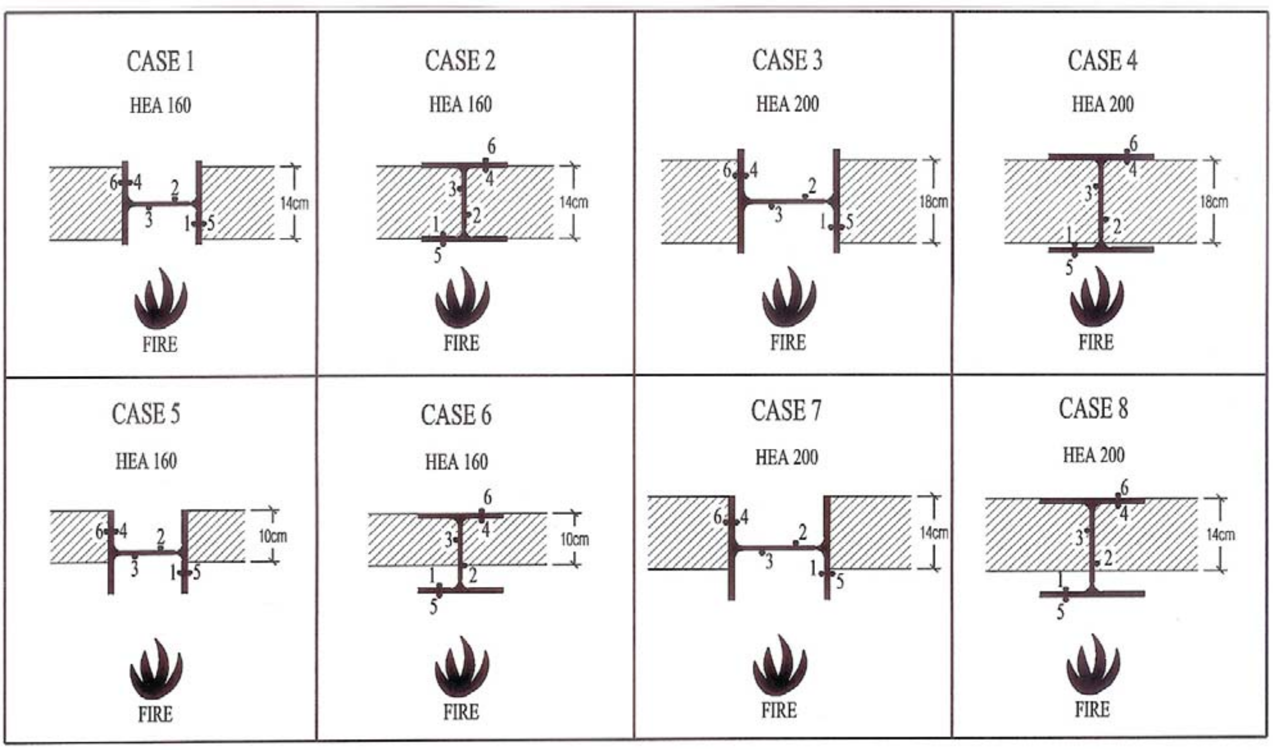


Fig. 3: Cases studied

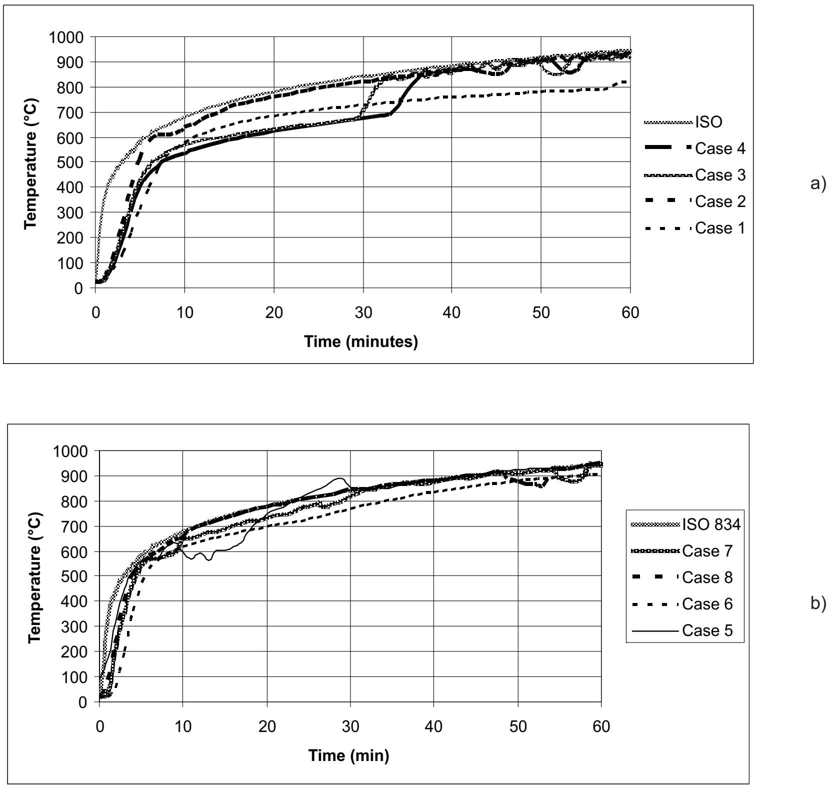


Fig. 4: Furnace curves a) cases 1 to 4 b) cases 5 to 8

specific weight = 1600 kg/m^3
specific heat × specific mass = 1344000 J/m3°C.

The emissivity was $\varepsilon = 0.7$ for the steel profile, and also for the masonry and the mortar.

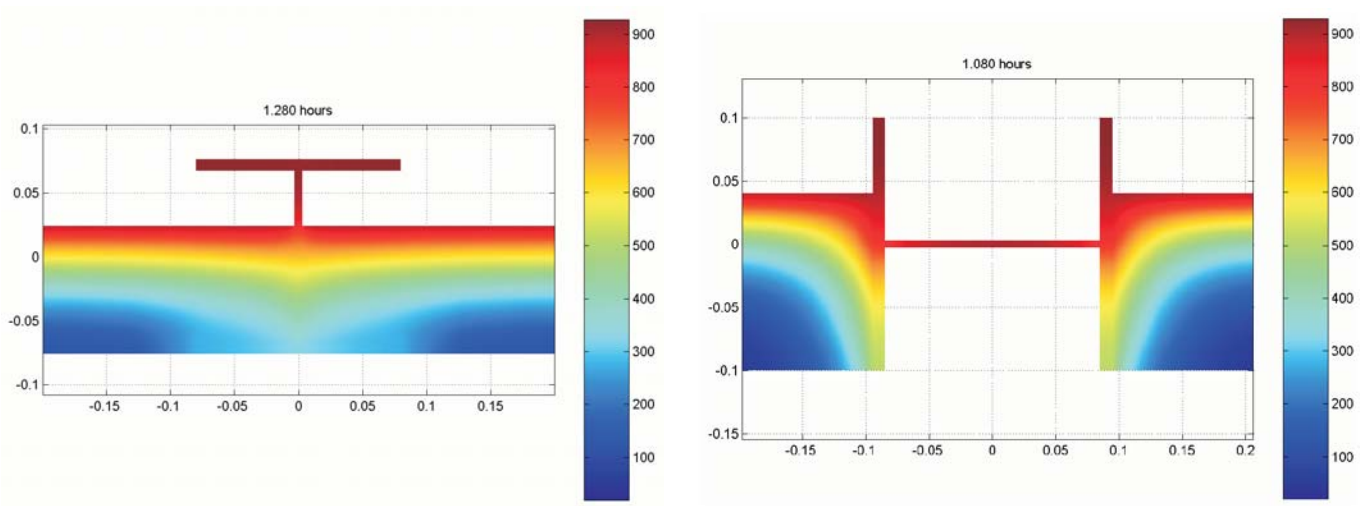
The coefficient of heat transmission by convection in the face exposed to the fire was $\alpha_c = 25$ W/m^2°C. For the non-exposed face, the values $\alpha_c = 4$ W/m^2°C and $\varepsilon = 0.7$ were used. These values led to better results.

The models were meshed in finite rectangular elements with sides of 4 mm × 5 mm. The STC computer code can draw isothermals and temperature fields, for each instant of time, and can rapidly give the value of the temperature as a function of time. The cases studied are summarized in Fig. 3.

4 Comparisons – experimental vs numerical analysis

4.1 Furnace temperatures

The temperatures inside the furnace were very uniform in both series of tests (cases 1 to 4 and 5 to 8), but a small delay to the ISO 834 fire curve is observed in the first series of four tests (cases 1 to 4) (Fig. 4). As already explained, this delay



a) b)

Fig. 5: Isothermals in the cross-section a) case 6, b) case 7

may be related to the type of thermocouples used in the furnace in the first series of tests.

4.2 Thermal gradients in the cross-sections

Fig. 5 shows the isothermals on the cross-section for cases 6 and 7. In case 6, the wall was 10 cm in thickness, and in case 7 it was 14 cm in thickness. The figure shows higher thermal gradients in the cross-section for case 6 than for case 7. The mechanical resistance of the steel profile is perhaps more affected in case 7.

4.3 Evolution of temperatures in the middle height section of the steel columns

The temperatures in the experimental tests were measured in six points of five 5 sections of the steel column (Fig. 1). The temperatures in the middle height section of the columns were compared with those obtained in numerical simulations for 60 min (Figs. 6 to 9). In these figures, th_1 stands for thinner walls, and th_2 stands for thicker walls.

In the case of the web parallel to the wall surface, the temperature in the flange not exposed to the fire (thermocouple 4 and 6), is higher in the case of walls of smaller thicknesses (Figs. 6a and 8a). For HEA160, the difference is nearly 100 °C for the STC calculations and for the experimental tests (Fig. 6a). For HEA200, the difference is almost 75 °C for both the STC calculations and the experimental tests (Fig. 8a).

In the face of the web exposed to the fire, the temperatures are higher for the thin walls than for the thick walls (thermocouple 3), presenting a very small difference between STC simulations and experimental tests (Fig. 8b).

In the case of the web perpendicular to the wall surface, the temperature in the exposed flange (thermocouple 5) is also higher in the case of the thin wall than the thick wall (Figs. 7a and 9a). For HEA160, the difference is approximately 50 °C in the STC simulations and almost the same in the experimental tests (Fig. 7a). For HEA200, the difference is about 100 °C in both analyses (Fig. 9a).

Curiously, in the unexposed flange the temperatures are higher for the thick wall (thermocouple 6), in the experimental tests. For HEA160, the difference is about 100 1C in the experimental test (Fig. 7b) and for HEA200 the results are very close in both analyses (Fig. 9b).

5 Conclusions

For cases with the web parallel to the wall surface, it was concluded that the thicker wall plays an important role in reducing the temperatures on the unexposed half of the flange and also in the web.

While for cases with the web perpendicular to the wall surface a quite interesting result was observed, in the unexposed face of the flange the temperatures were slightly higher when the wall was thicker. Conversely, on the exposed flange the temperatures were higher when the walls were thinner.

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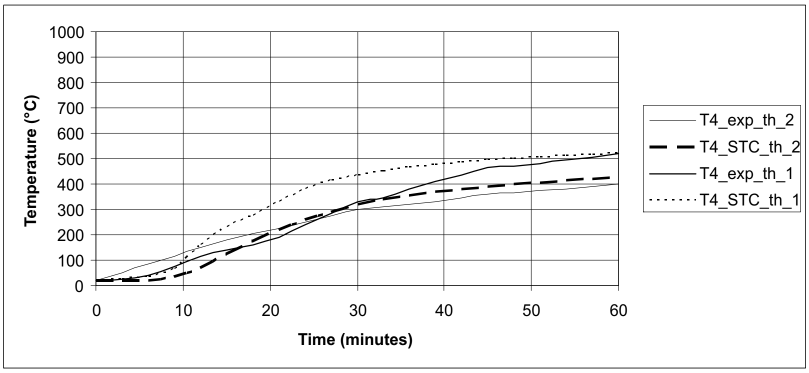
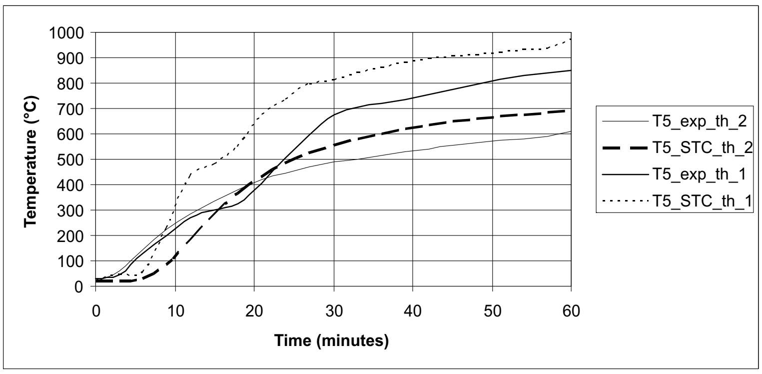


a)



b)

Fig. 6: Temperatures vs time for HEA160 with the web parallel to the wall (cases 1 and 5); a) thermocouple T4 ; b) thermocouple T5

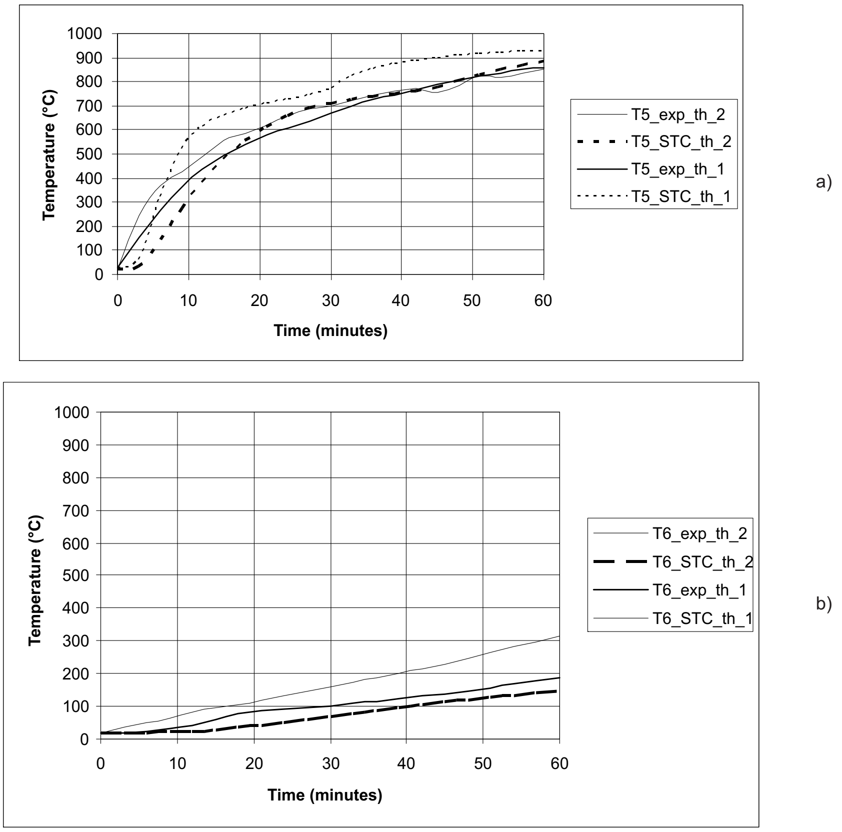


Fig. 7: Temperatures vs time for HEA 160 with the web perpendicular to the wall (cases 2 and 6); thermocouple T5; b) thermocouple T6

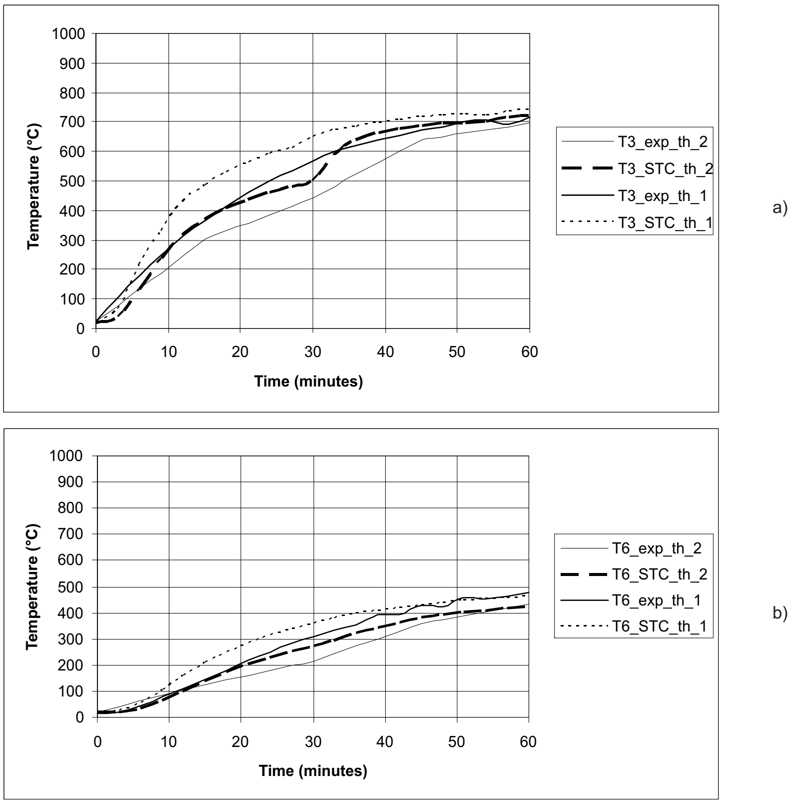
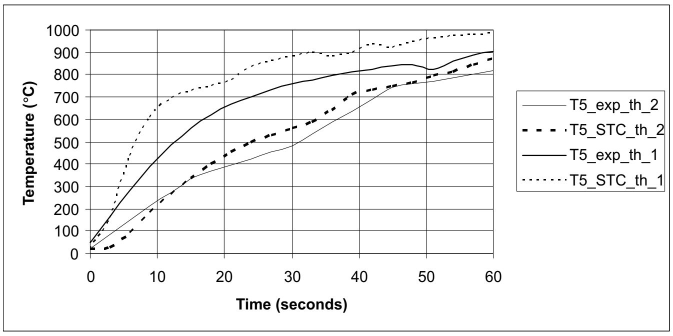
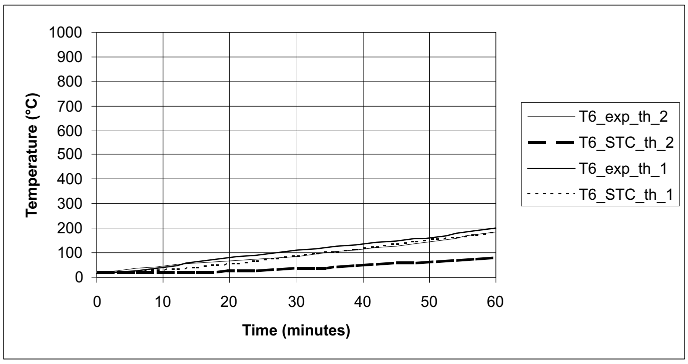


Fig. 8: Temperatures vs time for HEA 200 with the web parallel to the wall (cases 3 and 7); a) thermocouple T6 ; b) thermocouple T3



a)



b)

Fig. 9: Temperatures vs time for HEA 200 with the web perpendicular to the wall (cases 4 and 8); a) thermocouple T5 ; b) thermocouple T6

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