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ENHANCEMENT OF THE FIRE RESISTANCE OF CONCRETE-FILLED STEEL TUBULAR COLUMNS BY USING HIGH PERFORMANCE STEELS

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Abstract. *In recent years, innovative solutions have been developed with the purpose of increasing both the load-bearing capacity and fire resistance of concrete-filled steel tubular (CFST) columns. One of these solutions are the so-called concrete-filled dual steel tubular (CFDST) columns. In this configuration, the inner steel tube is thermally protected by the outer concrete ring and therefore its degradation is delayed, which may thus help resisting the applied load for a longer period of fire exposure time. An alternative solution that might be interesting to evaluate under fire conditions is to embed an inner steel profile inside the CFST section, such as an HEB profile.*

In addition to the development of new types of composite sections, the use of high strength steels (HSS) in construction is increasing, owing to their excellent mechanical properties, which may also be used for an enhanced fire resistance. In the same line, stainless steels (SS) are also becoming widely used in construction due to their beneficial characteristics such as corrosion resistance, high ductility or good aesthetics. Besides, the degradation of their strength and stiffness at elevated temperature is slower than for carbon steels, hence SS may withstand higher temperatures without significantly altering their mechanical properties.

This paper aims at obtaining strategies for enhancing the fire resistance of concrete-filled steel tubular columns with the use of innovative solutions (CFDST sections or embedded HEB profiles) combining high performance steels such as HSS or SS. Taking advantage of the improved mechanical properties of these steels at elevated temperatures and using the appropriate thickness ratio between the outer and inner tube or embedded steel profile, it may be possible to attain the required fire resistance without the need for external protection.

A three-dimensional finite element model is used in this paper for conducting parametric studies with the different section types and material combinations, in order to evaluate the interest of using HSS and SS for improving the fire performance of steel-concrete composite columns.

1 INTRODUCTION

The premature failure of slender CFST columns when exposed to fire was highlighted in previous investigations by the authors [1, 2]. Therefore, solutions are needed for improving the fire performance of this typology of composite columns.

In this paper, different innovative solutions are studied, which may solve the limitations of conventional CFST columns, such as concrete-filled dual steel tubular columns (CFDST) or columns with embedded HEB profiles (CFST-HEB), where the inner profiles are protected from the direct exposure to the fire by the surrounding concrete.

High strength steels (HSS) – with yield strength over 460 MPa – are acquiring an increasing popularity in the construction industry, owing to their excellent mechanical properties. The advantages of HSS open a new range of possibilities regarding their application in CFST columns, where they can result of great utility to solve the problem of the limited fire resistance of slender members. The existing literature on the fire behaviour of HSS is still scarce, although, in the last years, efforts have been made by researchers to characterize their mechanical properties at elevated temperature [3, 4]. The enhancement in fire resistance obtained by using HSS is also investigated in this paper.

The paper also explores the possibility of using stainless steel (SS) at the outer tube. Stainless steel tubular sections are also becoming widely used in construction due to their beneficial characteristics such as corrosion resistance, high ductility, or good aesthetics. Besides, their reduction in strength and stiffness at elevated temperature is slower than for carbon steels and, therefore, SS can be exposed to higher temperatures without significantly altering their properties. However, few models can be found to describe the thermal and mechanical properties of the different grades of SS [5, 6].

Compared to traditional carbon steels, SS have a high initial cost which may be overcome by using the material more efficiently in innovative solutions such as CFDST columns or columns with embedded HEB profiles, enhancing not only their strength but also their fire resistance. Authors such as Tao et al. [7] and Han LH et al. [8] recently carried out research on CFST columns with hollow steel tubes made of SS where their fire resistance was found to be much higher than those columns with carbon steel. Wang et al. [9] recently published a numerical study of CFDST stub columns with outer SS tube, where the improvement in both ultimate capacity and ductility obtained by using SS was evidenced, although this investigation was focused at ambient temperature.

2 NUMERICAL MODEL

2.1 General description of the numerical model

A three-dimensional finite element model has been developed by the authors through the general purpose nonlinear finite element analysis package ABAQUS [10]. This numerical model had been previously used with satisfactory results for simulating the fire behaviour of CFST columns and was also validated in previous work for other steel-concrete composite solutions such as double-tube sections or embedded HEB profiles [11].

The main features of the numerical model are hereafter described. Different parts are assembled in the model: outer steel tube, concrete encasement, inner profiles – steel tube or HEB profile – and steel end plates. These steel end plates are modelled as discrete rigid parts with all nodes coupled to a reference point located at the column axis. The axial load is applied to the upper rigid plate in the numerical simulations through its reference node.

The outer steel tube, concrete encasement and inner profiles are meshed using three-dimensional eight-noded solid elements with reduced integration (C3D8R). In turn, the steel end plates are meshed using four-noded three-dimensional bilinear rigid quadrilateral elements (R3D4). Based on the results of a mesh sensitivity study, a maximum finite element size of 20 mm is used. Fig. 1 shows an example of the finite element mesh for two of the geometries studied in this paper.

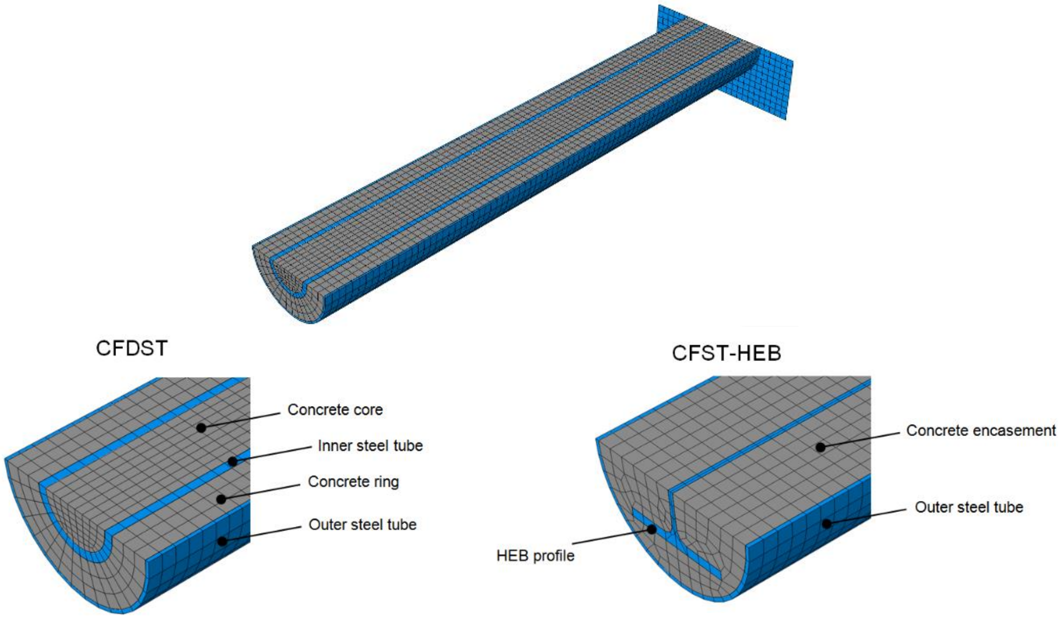

Figure 1: Finite element mesh for the different steel-concrete composite solutions studied.

The mechanical interaction between the contacting surfaces of the different steel profiles (outer tube or inner profiles) and the concrete encasement is modelled as follows. In the normal direction, a “hard point” contact formulation is used, which allows any pressure value when the surfaces are in contact and transmits no pressure when the surfaces do not contact. For the tangent interaction, the Coulomb friction model is employed, with a value of 0.3 for the friction coefficient.

The numerical model takes into account the initial geometric imperfection of the columns, obtained from a previous eigenvalue analysis as the first buckling mode shape of a hinged column, multiplied by an amplification factor equal to L/1000.

A sequentially coupled thermal-stress analysis is used in the simulations. This approach consists of first conducting a pure heat transfer analysis by computing the temperature field following by a stress/deformation analysis for calculating the structural response. In the initial thermal analysis, the columns are uniformly exposed to the standard ISO-834 fire curve along their whole length. In the mechanical analysis, the columns are first loaded and the constant applied load is maintained, while the output from the thermal analysis (nodal temperature-time curves) is imported into the mechanical model as a predefined field, representing the temperature evolution inside the column during the fire exposure.

The thermal resistance at the boundary between the outer steel tube and the concrete encasement is taken into account in the numerical model. A constant gap conductance value of 200 W/m^{2}K is used for modelling the thermal resistance at this interface.

The temperature dependent thermal and mechanical properties of the materials are accounted for in the numerical model. To represent the mechanical behaviour of steel, an isotropic elastic-plastic model with the von Mises yield criterion is used. The constitutive model for the uniaxial behaviour of normal strength steel at elevated temperatures is taken from EN 1993-1-2 [12]. The Poisson's ratio of steel is assumed to be independent of the temperature, being equal to 0.3. Moreover, the temperature dependent thermal properties of steel given in EN 1993-1-2 are adopted – specific heat, thermal conductivity and thermal elongation –.

For modelling high strength steel (HSS) at elevated temperatures, the shape of the constitutive laws given in EN 1993-1-2 is used, together with the reduction factors proposed by Qiang et al. [4], as the model in EN 1993-1-2 applies only to steel grades up to S460. Regarding stainless steel, the thermal and mechanical properties at elevated temperature are taken from Annex C in EN 1993-1-2 [12].

For characterizing the mechanical behaviour of concrete at elevated temperatures, a Drucker Prager model is used in ABAQUS [10]. The stress-strain relations for concrete under compression given in EN 1992-1-2 [13] are employed. The possible confinement offered by the outer an inner steel tube to the concrete was not accounted for implicitly in the uniaxial constitutive stress-strain model, but considered explicitly through the yield surface and plastic flow rule in the Drucker-Prager plasticity model, where the yield behaviour of the material depends on the equivalent pressure stress. However, the enhancement of the concrete strength by confinement weakens in the fire event due to the rapid degradation of the steel tube at elevated temperature and thus its effect is less influential than at ambient temperature.

The Poisson's ratio of concrete is assumed to be independent of the temperature, being equal to 0.2. The thermal properties for concrete at elevated temperatures are obtained from EN 1992-1-2.

2.2 Validation of the numerical model

The described numerical model was validated in a previous work by the authors against experimental tests on the two types of sections studied: concrete-filled dual steel tubular columns (CFDST) and CFST columns with embedded HEB profiles (CFST-HEB). The details of the specimens compared and the validation results can be seen in [11].

For the first type of sections, CFDST, the model was validated against own tests [14], as well as with reported tests from a previous research by Lu et al. [15]. Examples are given in Fig. 2. It can be seen that the numerical model predicts well the fire behaviour of this type of composite columns, with a good estimation of the axial displacement along the fire exposure time, capturing well the elongation of the outer steel tube and its subsequent yielding and shortening due to thermal degradation. For the case of CFST-HEB columns, the experimental results from Dotreppe et al. [16] were used for validation.

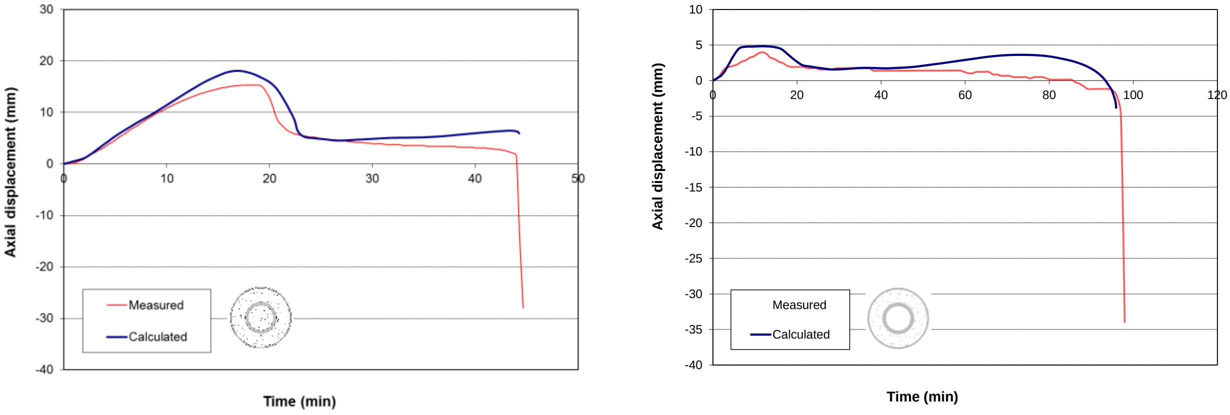

Figure 2: Comparison between numerical simulations and experimental axial displacement curves: a) C200-6-30_C114-3-30 [14], b) CC2 [15].

3 PARAMETRIC STUDY

3.1 Definition of analysis cases

A parametric study is carried out in order to analyse the interest of using the innovative sections proposed in this paper for improving the fire performance of CFST columns. An initial CFST section of 273×12.5 mm is chosen as reference, and the amount of steel employed by that section is used to generate other two innovative sections with inner steel profiles (CFDST and CFST-HEB), see Fig. 3.

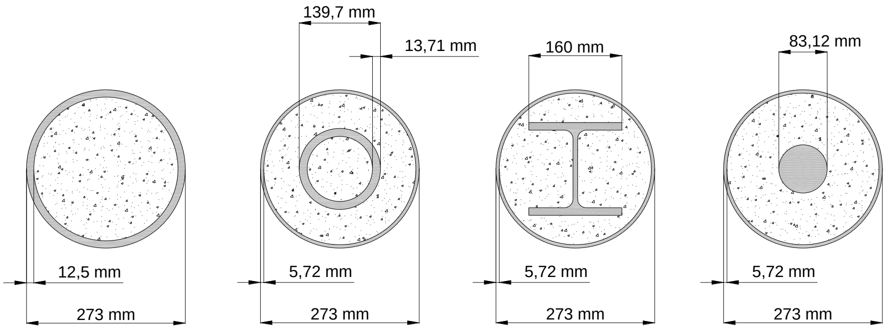

Figure 3: Cross-sectional dimensions used in the parametric study: a) CFST; b) CFDST; c) CFST-HEB.

Two different series of numerical simulations are conducted in this parametric study. In SERIES 1 (Fig. 3), all the columns have exactly the same quantity of steel split into the two profiles (inner + outer) – i.e. same total steel cross-sectional area –, while in SERIES 2 all the columns have the same axial load-bearing capacity at room temperature.

The length of all the columns analysed is 3240 mm and pinned-pinned boundary conditions are used in all the numerical simulations, resulting in a relative slenderness of 0.5 in the case of the reference CFST column. The steel grade of all the outer tubes is S355, while C30 concrete is used for the encasement. A concentric axial load of 1408.80 kN is applied to all the columns, corresponding to a 30% of the maximum capacity of the CFST column at room temperature.

SERIES 1

In the first group of columns, the grade of the inner steel tube or HEB profile is increased progressively from S355 to S960, while maintaining the same steel area. The geometrical and mechanical features of the columns analysed in this series are summarized in Table 2. It is worth noting that the differences in terms of room temperature load bearing capacity, for those columns using S355 steel at the inner profile (CFST, CFDST-01 and CFST-HEB-01) range between a 3% and a 5%, therefore the three columns would perform in a similar way at room temperature, while showing identical external appearance and using the same amount of steel.

The possibility of enhancing the fire resistance of the columns by using stainless steel at the outer tube is also studied. For that purpose, the previous series of analysis are repeated by replacing the outer tube of carbon steel (S355) with an equivalent one made of stainless steel. Hollow SS tubes of grade CP350 (austenitic stainless steel 1.4301) are selected, with a 0.2% proof strength of 350 MPa. The details of this new group (SERIES 1SS) are given in Table 3.

Table 2: Details of the columns analysed in SERIES 1 (same steel area)

Specimen	**Outer profile (mm)**	**Inner profile (mm)**	f_{yo} **(MPa)**	f_{yi} **(MPa)**	$\bar{\lambda}$	$N_{b,Rd}$ / $N_{b,Rd(\text{CFST})}$	μ **(%)**	**Time (min)**
CFST	273x12.5	-	355	-	0.50	1	0.30	28
CFDST-01	273x5.72	139.7x13.71	355	355	0.59	0.97	0.31	77
CFDST-02	273x5.72	139.7x13.71	355	460	0.63	1.06	0.28	94
CFDST-03	273x5.72	139.7x13.71	355	690	0.69	1.25	0.24	120
CFDST-04	273x5.72	139.7x13.71	355	960	0.76	1.45	0.21	141
CFST-HEB-01	273x5.72	HEB160	355	355	0.60	0.96	0.31	47
CFST-HEB-02	273x5.72	HEB160	355	460	0.63	1.05	0.28	57
CFST-HEB-03	273x5.72	HEB160	355	690	0.70	1.24	0.24	71
CFST-HEB-04	273x5.72	HEB160	355	960	0.77	1.44	0.21	86

Table 3: Details of the columns analysed in SERIES 1SS (same steel area)

Specimen	**Outer profile (mm)**	**Inner profile (mm)**	$f_{0.2\%o}$ **(MPa)**	f_{yi} **(MPa)**	$\bar{\lambda}$	$N_{b,Rd}$ / $N_{b,Rd(\text{CFST})}$	μ **(%)**	**Time (min)**	**Diff.**
CFDST-SS-01	273x5.72	139.7x13.71	350	355	0.60	0.96	0.31	93	20.78%
CFDST-SS-02	273x5.72	139.7x13.71	350	460	0.64	1.05	0.29	110	17.02%
CFDST-SS-03	273x5.72	139.7x13.71	350	690	0.70	1.24	0.24	136	13.33%
CFDST-SS-04	273x5.72	139.7x13.71	350	960	0.77	1.44	0.21	156	10.64%
CFST-HEB-SS-01	273x5.72	HEB160	350	355	0.61	0.95	0.31	62	31.91%
CFST-HEB-SS-02	273x5.72	HEB160	350	460	0.64	1.05	0.29	72	26.32%
CFST-HEB-SS-03	273x5.72	HEB160	350	690	0.71	1.23	0.24	89	25.35%
CFST-HEB-SS-04	273x5.72	HEB160	350	960	0.78	1.43	0.21	94	9.30%

SERIES 2

A second series of numerical simulations (SERIES 2) is performed by equalling all the columns in terms of axial load-bearing capacity at room temperature, using the different section types and steel grades (S355 to S960) of the previous analysis. The geometrical and mechanical features of the columns in this series are summarized in Table 4. The dimensions of the inner profiles of the different types of columns studied have been varied so as to obtain the same axial buckling load at room temperature as that of the reference CFST column.

Table 4: Details of the columns analysed in SERIES 2 (same room temperature capacity)

Specimen	**Outer profile (mm)**	**Inner profile (mm)**	f_{yo} **(MPa)**	f_{yi} **(MPa)**	$\bar{\lambda}$	A_s / $A_{s(\text{CFST})}$	μ **(%)**	**Time (min)**
CFST	273x12.5	-	355	-	0.50	1	0.30	28
CFDST-05	273x5.72	139.7×15.50	355	355	0.60	1.06	0.30	85
CFDST-06	273x5.72	139.7×11.48	355	460	0.61	0.92	0.30	46
CFDST-07	273x5.72	139.7×7.36	355	690	0.63	0.77	0.30	71
CFDST-08	273x5.72	139.7×5.19	355	960	0.63	0.68	0.30	60
CFST-HEB-05	273x5.72	HEB160	355	355	0.60	1.00	0.31	47
CFST-HEB-06	273x5.72	HEB140	355	460	0.62	0.89	0.31	47
CFST-HEB-07	273x5.72	HEB120	355	690	0.65	0.80	0.29	44
CFST-HEB-08	273x5.72	HEB100	355	960	0.67	0.72	0.29	35

For the case of the CFST-HEB columns, it was not possible to obtain exactly the same load value as the reference one, since commercial dimensions were used for the HEB profiles, producing only small differences.

It is worth noting in Table 4 that the amount of steel needed in the section decreases as the steel grade is increased, up to a 68% in the case of the CFDST column (CFDST-08) as compared with the reference CFST column. This means that the same load-bearing capacity at room temperature can be reached with important material savings when using HSS at the inner profiles, although the differences in cost of the higher steel grades should be also evaluated.

Similarly, this second series is studied with stainless steel at the outer tube. The details of this new group (SERIES 2SS) are given in Table 5.

Table 5: Details of the columns analysed in SERIES 2SS (same room temperature capacity)

Specimen	**Outer profile (mm)**	**Inner profile (mm)**	$f_{0.2\text{‰}}$ **(MPa)**	f_{yi} **(MPa)**	$\bar{\lambda}$	$A_s / A_{s(CFST)}$	μ **(%)**	**Time (min)**	**Diff.**
CFDST-SS-05	273x5.72	139.7×15.50	350	355	0.60	1.06	0.30	101	18.82%
CFDST-SS-06	273x5.72	139.7×11.48	350	460	0.61	0.92	0.30	59	28.26%
CFDST-SS-07	273x5.72	139.7×7.36	350	690	0.63	0.77	0.30	89	25.35%
CFDST-SS-08	273x5.72	139.7×5.19	350	960	0.63	0.68	0.30	74	23.33%
CFST-HEB-SS-05	273x5.72	HEB160	350	355	0.60	1.00	0.31	62	31.91%
CFST-HEB-SS-06	273x5.72	HEB140	350	460	0.62	0.89	0.31	60	27.66%
CFST-HEB-SS-07	273x5.72	HEB120	350	690	0.65	0.80	0.29	55	25.00%
CFST-HEB-SS-08	273x5.72	HEB100	350	960	0.67	0.72	0.29	46	31.43%

The results of the numerical simulations for the different series of the parametric studies are given in the last columns of the previous tables, where the values of the failure times are summarized (fire resistance time in minutes) and evaluated in the following sections. The percentage of increase achieved by replacing the outer carbon steel tube with a stainless steel one is given under the label “Diff.” in Tables 3 and 5.

3.2 Comparison for equal steel area (SERIES 1)

The effect of the cross-section configuration can be seen in Table 2 by comparing those cases using the same steel grade, for instance S355. The reference CFST column presented a very limited fire resistance time of only 28 minutes. With the CFST-HEB solution, using an inner HEB160 profile, the fire resistance time of the column is increased up to 47 minutes (CFST-HEB-01). If the steel tube is split into two tubes, generating the CFDST column with the ticker tube at the inner part of the section, the fire resistance time is significantly improved to 77 minutes (CFDST-01). Therefore, it is proved that a good strategy for enhancing the fire resistance of traditional CFST columns is to split the outer steel tube into two concentric tubes or a thinner tube plus an inner steel profile, which is thermally protected by the concrete encasement, delaying its degradation at elevated temperatures. Note that these solutions make use of the same amount of steel and concrete, whilst maintaining the same external dimensions of the columns.

As can be seen in Table 2, the fire resistance of these innovative solutions can be further increased by using high strength steels (HSS) at the inner profiles. In the case of the CFST-HEB, the fire resistance time increases from 47 to 57 minutes using an inner profile made of S460 (CFST-HEB-01 vs CFST-HEB-02). In turn, for the CFDST solution, a noticeable increase from 77 to 94 minutes is obtained (CFDST-01 vs CFDST-02).

If the grade of the inner steel tubes is further increased to S690 or S960, the enhancement of the fire resistance is more noticeable. Fire resistance times of 120 and 141 minutes are reached for the case of the double-tube column (CFDST-03 and CFDST-04), or 71 and 86 minutes for the CFST-HEB column (CFST-HEB-03 and CFST-HEB-04). A general comparison is shown in Fig. 4 for S960 steel at the inner profiles, superimposed with the results for the reference S355 steel. This graph shows the axial displacement versus time curves obtained from the numerical simulations.

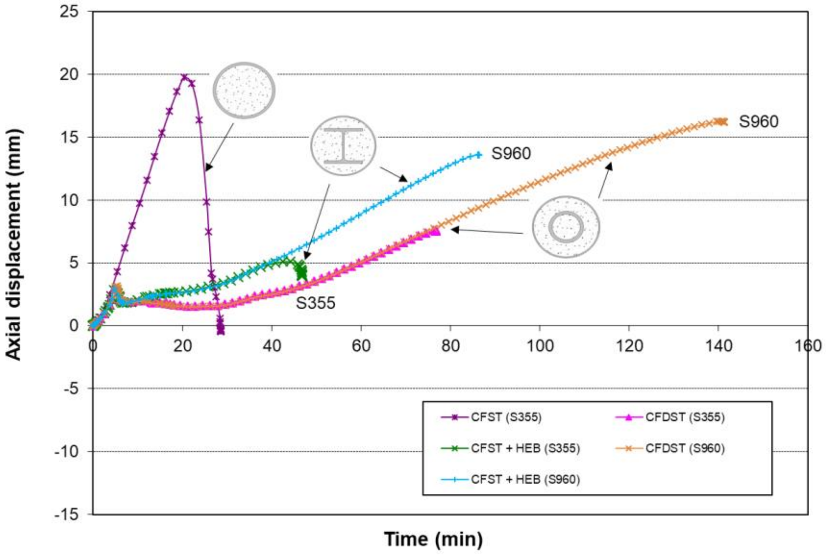

Figure 4: Comparison between the cross-section configurations studied, using different steel grades and equal steel area (S355 vs S960).

It should be noted that, apart from increasing the fire resistance time of the columns, their maximum capacity at room temperature is significantly increased by using a higher grade of steel at the inner profiles (see Table 2), while maintaining the outer dimensions. This increase in load-bearing capacity can reach a 45% in the case of using S960 steel on a CFDST section (CFDST-04). Therefore, as this numerical study proves, by using HSS at the inner profiles both the load-bearing capacity of the columns at room temperature and their fire resistance can be enhanced at the same time. However, it is worth noting that the load applied to all the columns in SERIES 1 was constant and thus the corresponding reduction of the degree of utilization for increasing steel grades should be taken into account in design.

3.3 Enhancement obtained by using stainless steel at the outer tube (SERIES 1SS)

The results of the numerical simulations for SERIES 1SS (same area) are given in Table 3. The last column of this table indicates the enhancement in fire resistance time (in percentage) obtained by replacing the outer steel tube by one of equal dimensions made of stainless steel.

As it can be seen, an increment up to 94 minutes may be obtained with the CFST-HEB solution in the case of using an inner steel tube with grade S960, while the fire resistance time can be enhanced up to 156 minutes with the CFDST solution. Nevertheless, the relative increment with respect to the same case of SERIES 1 (with outer tube made of carbon steel) is higher for the combinations with lower steel grade at the inner tube (20.78% increase for specimen CFDST-SS-01 vs 10.64% increase for specimen CFDST-SS-04, or 31.91% for specimen CFST-HEB-SS-01 vs 9.30% for specimen CFST-HEB-SS-04), what suggests that the enhancement provided by the stainless steel outer tube results more beneficial for composite columns with normal steel grades at the inner tubes.

For the case with lowest inner steel grade (S355), the enhancement obtained by using an outer stainless steel tube is illustrated in Fig. 5. For the CFDST solution, the fire resistance time is increased from 47 to 62 minutes (31.91%), while for the CFST-HEB solution, an increment from 77 to 93 minutes is obtained (20.78%). The increment achieved with respect to the reference CFST column with carbon steel grade S355 is noticeable, using the same total steel area.

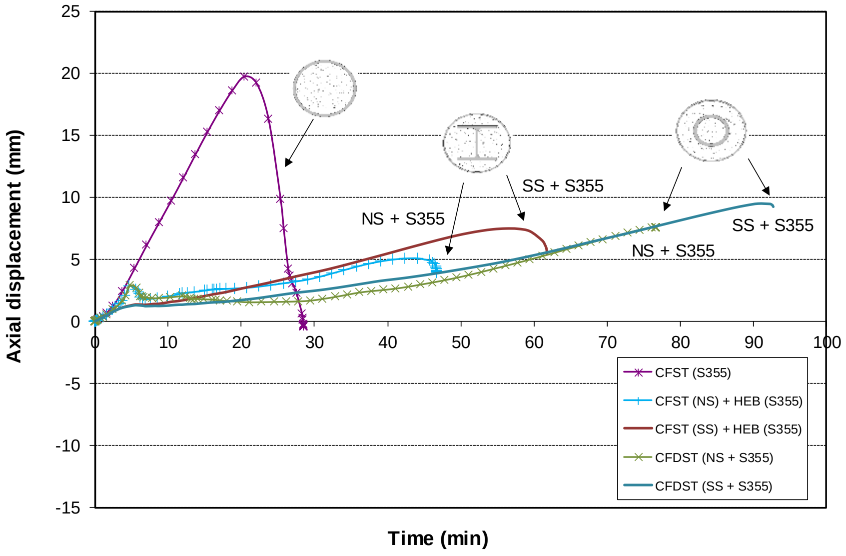

Figure 5: Effect of using stainless steel at the outer tube, for equal steel area (inner profiles with S355).

Note that a fire resistance time higher than 90 minutes may be reached by combining an outer tube made of stainless steel with an inner tube of carbon steel of S355 (93 min), leading to a higher fire resistance than that of the best combination of CFST-HEB (86 min), therefore this alternative should be considered in design.

3.4 Comparison for equal room temperature capacity (SERIES 2)

The results obtained in the second series of numerical simulations (same room temperature capacity) are given in Table 4. As it can be seen, if the steel grade is improved whilst maintaining the same room temperature capacity of the columns, the enhancement in fire resistance is not so clear, as the dimensions of the inner profiles for getting this equivalence need to be progressively reduced as their yield strength is increased. For the case of CFDST columns, the higher fire resistance time is obtained with the solution using S355 steel, followed by S690, S960 and finally S460. In any case, the columns with higher steel strengths make use of a smaller inner section and therefore less amount of steel, with the consequent material savings. Therefore, if the room temperature capacity is taken as reference, different factors should be taken into account when deciding on what the optimal solution should be. The axial displacement versus time curves for the cases with inner steel profile S355, compared with those using HSS S960 are plotted in Fig. 6, where the described effect is noticeable.

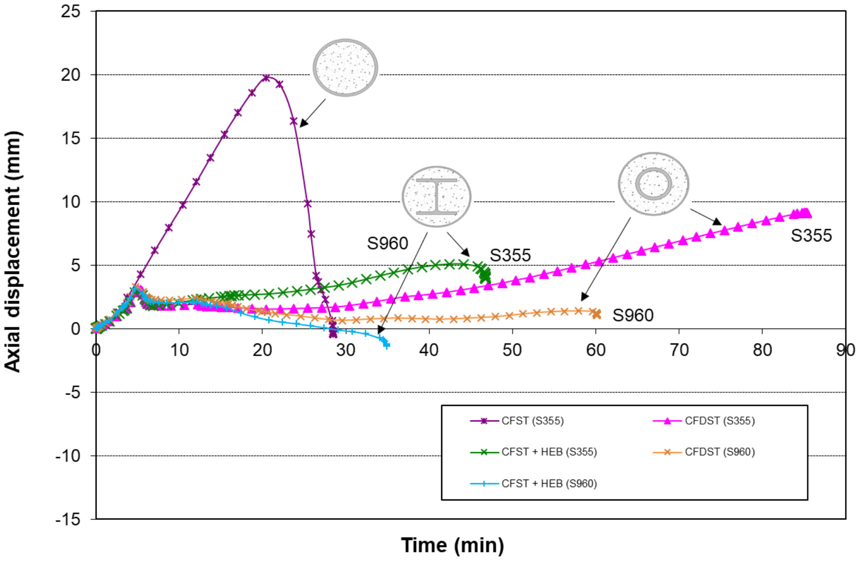

Figure 7: Comparison between the cross-section configurations studied, using different steel grades and equal room temperature capacity (S355 vs S960).

3.5 Enhancement obtained by using stainless steel at the outer tube (SERIES 2SS)

The results of the numerical simulations for SERIES 2SS (same room temperature capacity) are given in Table 5, where the last column indicates the enhancement in fire resistance time (in percentage) obtained by replacing the outer steel tube by one of equal dimensions made of stainless steel. The best solution in this case is obtained with the combination of inner steel tube of normal grade S355, reaching 101 minutes for the CFDST solution, followed by the combination with inner tube of S690. Nevertheless, the higher relative increase as compared with SERIES 2 is obtained with the specimen using S460 steel at the inner tube, increasing its fire resistance time from 46 to 59 minutes (28.26% relative increase). For the CFST-HEB solution, the best combination is again obtained with S355 steel at the inner tube, followed by S460, although in this case the relative increase obtained with the stainless steel is more noticeable for both S355 and S960 cases. Therefore, it is not easy to draw a conclusion on what is the best combination in this case, which should be a balance between attaining sufficient fire resistance time without increasing excessively the steel usage and therefore the cost of the column.

The enhancement obtained by using an outer stainless steel tube is shown in Fig. 8 for the case with lowest inner steel grade (S355). For the CFST-HEB solution, the fire resistance time is increased from 47 to 62 minutes (31.91%) while for the CFDST solution, an increment from 85 to 101 minutes is obtained (18.82%). The enhancement obtained in this last case with respect to the initial CFST column with carbon steel grade S355 is remarkable, having the same ultimate capacity at room temperature. Note that this combination is superior in terms of fire performance that any of the group from SERIES 2 with inner HSS tubes, meaning that in the case of keeping the ultimate capacity at room temperature unaltered (same degree of utilization in fire), it should be recommended to use an outer tube of stainless steel and an inner profile with carbon steel of normal strength.

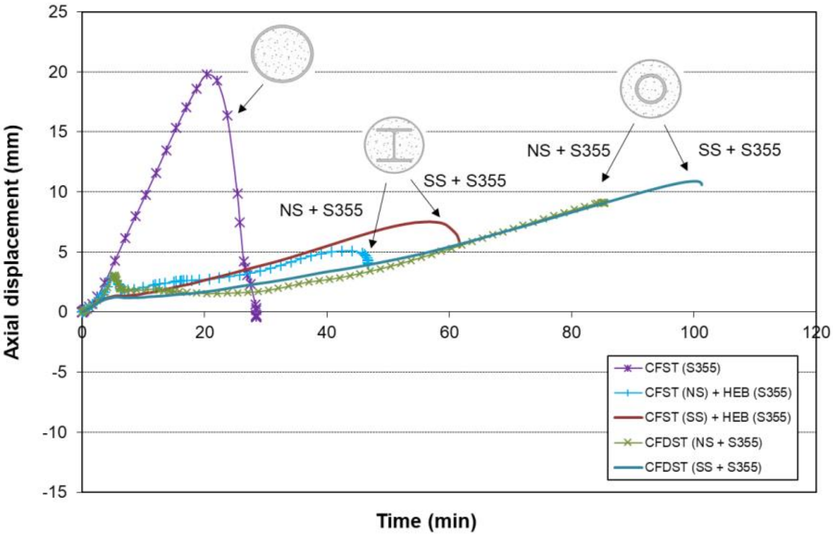

Figure 8: Effect of using stainless steel at the outer tube, for equal room temperature capacity (inner profiles with S355).

4 CONCLUSIONS

This paper presented a numerical study for investigating the fire behaviour of innovative steel-concrete composite columns using inner steel profiles, in order to propose strategies for enhancing the fire resistance of conventional CFST columns. A finite element model was developed and validated for the different types of sections studied. The influence of the cross-section type and the use of high performance steels (HSS at the inner profiles or SS at the outer tube) over the fire endurance of the columns was assessed through a parametric study.

It has been proved that a good strategy for enhancing the fire resistance of CFST columns is to split the outer steel tube into two profiles using most of the steel at the inner profile, which is thermally protected by the concrete encasement in the fire situation.

If the steel grade of the inner profiles is increased by using HSS, for the same steel usage, both the load-bearing capacity of the columns at room temperature and their fire resistance time are enhanced, although it must be taken into account that this comparison was performed under the same axial load applied and, therefore, the degree of utilization decreases with an increment in the steel grade. Moreover, the differences in cost related to using HSS at the inner profiles should be evaluated.

If the load-bearing capacity of the column at room temperature is maintained, the enhancement in fire resistance becomes not so clear when the steel grade is improved, as this equivalence leads to reduced dimensions of the inner profiles for increasing yield strengths and thus higher column slenderness. However, important material savings may be obtained when using HSS at the inner profiles with a reduction in the steel area.

Finally, an interesting option has been found based on using stainless steel at the outer tube, providing a significant enhancement in terms of fire resistance time under both scenarios. This solution can be an alternative to the use of HSS at the inner profiles, or may be used in combination with HSS for getting the best fire performance. The results of this study should be also evaluated in terms of material costs, in order to reach more solid conclusions.

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