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Hollow steel section columns filled with self-compacting concrete under ordinary and fire conditions

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Abstract

The present thesis is dedicated to the studies of hollow steel section columns filled with self-compacting concrete (SCC) under ordinary and fire conditions. The type of cross-section concerned is small sections with dense reinforcement or embedded steel profile where SCC is needed. The main objectives of the thesis are outlined as follows:

- Perform experimental investigation on the behaviour of steel hollow section columns filled with self-compacting concrete under standard fire conditions.

- Undertake extensive investigation on concrete filled steel hollow section (CFSHS) columns with small sections and dense reinforcement or embedded steel profile where self-compacting concrete is used. This type of columns is studied under both ordinary and fire conditions.

- Provide consulting engineers with a simplified method for calculating the fire resistance of CFSHS columns of small sections and dense reinforcement or embedded steel profile which have not been considered anywhere. Practical recommendations will also be given for columns of larger cross-sectional dimensions.

To achieve these goals, the state of the art regarding CFSHS columns under both ordinary and fire conditions was first presented.

Then numerical models using SAFIR computer code for analysis of CFSHS columns under ordinary and fire conditions were verified in thermal and structural analysis. Tests results from literature were used to validate the computer code. Some calibrations have been performed.

Afterwards, using the verified model, the ultimate load of CFSHS columns at normal temperatures was calculated with varying parameters such as cross-section dimensions, reinforcement ratios, concrete strengths and concrete covers. The type of cross-section concerned is small sections with dense reinforcement or embedded steel profile where SCC is needed. This type of cross-section is not included in existing design methods of Eurocodes. Simulation results are used to check if the current design method of EN 1994-1-1 is still valid for this type of cross-section and to see which European buckling curve is relevant for CFSHS columns with dense steel bar reinforcement or embedded steel profile. Curve “b” is suggested for this type of cross-section.

A new experimental research on steel hollow section columns filled with self-compacting concrete under standard fire tests was performed at University of Liege – Belgium. Results from these tests are used to verify the numerical models using SAFIR code for the analysis of CFSHS under fire conditions with the use of SCC. The aim of these calculations is to see whether the thermal and mechanical properties of self-compacting concrete are close to those of normal concrete. It is found that the material laws of normal vibrated concrete can be

applied for self-compacting concrete.

In order to give to consulting engineers more practical tools, a formula for calculating the fire resistance of SHS columns filled with concrete has been established. The field of applicability has been extended: effective length of column from 2 m to 7 m, percentage of reinforcing steel from 3.5 % to 10 %. Sections containing other steel profile are considered also. A formula for short columns with square section has been established based on SAFIR simulations taking into account the main parameters (quality of materials, dimensions, steel bars, and concrete cover). Further developments aim at showing whether the simplified equation can be used for other types of cross-sections, how the formula can be extended to slender columns, and how to treat columns with eccentric load.

After concentrating on CFSHS columns with small cross-section dimensions only (less than 300 mm), it is found that the fire resistance of such small sectional columns is quite low. In order to get additional practical information, *chapter VII* contains numerical calculations of the fire resistance of larger profiles (dimensions up to 400 mm). The main objective of these numerical calculations is to provide practical recommendations and data for immediate use by practical engineers.

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Notations

A_c cross-section area of concrete

A_s cross-section area of reinforcement

A_a cross-section area of the structural steel section

d diameter of circular section or the outside dimension of square section

Dr distance between the axis of longitudinal reinforcements and the border of the concrete core (concrete cover)

E_s modulus of elasticity of the reinforcing steel

E_a modulus of elasticity of the structural steel

E_{cm} secant modulus of elasticity of the concrete

$(EI)_{md}$ modified effective rigidity of the section after 10 minutes of fire

f_{cm} mean value of the measured cylinder compressive strength of concrete

f_{ck} characteristic value of the cylinder compressive strength of concrete

f_{sk} characteristic value of the yield strength of reinforcing steel

f_y nominal value of yielding strength of structural steel

f_{cd} design value of the cylinder compressive strength of concrete

f_{sd} design value of the yield strength of reinforcing steel

f_{yd} design value of yielding strength of the structural steel

f_c value of the cylinder compressive strength of concrete using in numerical simulations

f_s value of the yield strength of reinforcing steel using in numerical simulations

I_a second moment of area of the structural steel section

I_c second moment of area of the concrete section

I_s second moment of area of the reinforcement for the bending plane being considered.

L_{10} effective length corresponding to a fire resistance of 10 minutes of a column under determined loads.

l effective length of the column

N_c compressive resistance of the concrete portion: $N_c = A_c * f_c$

N_a compressive resistance of the steel wall portion: $N_a = A_a * f_y$

N_s plastic compressive resistance of the steel reinforcement portion: $N_s = A_s * f_s$

N_d compression load to column under normal temperature

N_{fi} axial load on the column during exposed to fire

N_{cr} elastic buckling load of the column

$N_{R10,R}$ compression load bearing capacity of the column after 10 minutes of fire

$N_{pl,Rk}$ characteristic value of the plastic resistance to compression of the section

$N_{pl,Rd}$ design value of plastic resistance to compression of the section

N_{Rd} ultimate design axial load of the column

$N_{R10,pl,R}$ compression plastic resistance of the section after 10 minutes of fire

$N_{R10,plR}$ the plastic resistance of the section after 10 minutes of fire

N_{u} ultimate load of the column at room temperature

$N_{u.fy=0}$ ultimate load of the column at room temperature ignored the strength of steel wall (calculated with f_y =0)

R_{f} fire resistance of slender column

R_{short} fire resistance of short column

t wall thickness of the steel hollow section

α imperfection parameter

χ reduction factor for flexural buckling

$\bar{\lambda}$ relative slenderness of the column

$\bar{\lambda}_{R10}$ relative slenderness of the column after 10 minutes of fire