BULLETIN No. 26

Fire Protection

CANADIAN STEEL CONSTRUCTION COUNCIL

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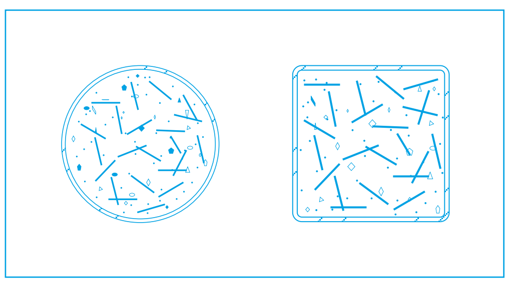
FIRE RESISTANCE OF STEEL-FIBRE REINFORCED CONCRETE-FILLED STEEL HSS COLUMNS

INTRODUCTION

The National Research Council of Canada (NRCC), in a joint effort with the Canadian Steel Construction Council (CSCC), and with support from IPSCO Inc. and the American Iron and Steel Institute (AISI), has recently completed the third phase of the ongoing research programme studying the fire endurance of steel HSS (Hollow Structural Sections) columns filled with concrete.

The first phase of the project studied the behaviour of concentrically loaded, round and square HSS columns filled with plain concrete and was the subject of Fire Protection Bulletin #21. The design formula and curves were subsequently published in Appendix D of the 1995 National Building Code of Canada which gives guidance on the calculation of fire-performance ratings. The second phase of the project studied the behaviour of concentrically loaded, round and square HSS columns filled with bar-reinforced concrete and was the subject of Fire Protection Bulletin #25.



The present study introduces steel-fibre reinforcement as a means of obtaining nominally higher load capacities and longer fire endurance periods when compared to plain filling but without the added expense of bar-reinforcing. Research staff at the Institute for Research in Construction (IRC), have published a number of reports (1, 2, 3, 4, 5) describing the results.

TEST PROGRAMME

The work on concentrically loaded HSS columns filled with steel-fibre reinforced concrete was completed in 1996 and a paper entitled 'Design Equations for Evaluating Fire Resistance of SFRC-Filled HSS Columns', authored by V.K.R. Kodur was published in the ASCE Journal of Structural Engineering in June 1998 (6). Thirteen loaded, full scale columns were tested in accordance with the ULC S101 (7) and ASTM E119 (8) fire test standards. The steel fibres used were 50 mm long and had a 0.9 mm diameter. The researchers felt that 25 mm long steel fibres would give similar results. A steel-fibre content of 1.76% by mass was felt to be the optimal value. Data from the fire tests were used to validate a numerical model which incorporated realistic stress-strain relationships and the thermal properties for structural steel and steel-fibre reinforced concrete at elevated temperatures. Using the model, computer simulated fire tests were conducted to determine the influence of various factors on the fire endurance. The results from the parametric study were used to develop a simplified expression for fire resistance design.

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DESIGN FORMULA AND CURVES

Concentrically loaded hollow steel columns that are filled with steel-fibre reinforced concrete and are fabricated and erected within the tolerances as stipulated in CAN/CSA-S16.1, "Limit States Design of Steel Structures" shall be assigned a fire-resistance rating, R, provided:

$C \leq C_{max}$

where

$C =$ *axial compressive force due to dead and live loads without load factors, kN,*

$$C_{max} = \left(\frac{a \left(f_c' + 20 \right) D^{2.5}}{R \left(KL - 1000 \right)} \right)^2$$ *but shall not exceed 1.1 times the factored compressive resistance of the concrete core,* C_r', *in accordance with CAN/CSA-S16.1,*

$a =$ *constant (See Table 1)*

$f_c' =$ *specified compressive strength of concrete in accordance with CSA-A23.3, "Design of Concrete Structures," MPa,*

$D =$ *outside diameter of a round column or outside width of a square column, mm,*

$R =$ *specified fire endurance period, min,*

$KL =$ *effective length of column as defined in CAN/CSA-S16.1, mm;*

subject to validity limits:

f_c' *20 MPa to 55 MPa,*

D *141 mm to 406 mm for round columns, 102 mm to 305 mm for square columns,*

steel-fibres shall be 25 to 50 mm in length and be ≥1.75% of the concrete mix by mass.

R *≤ 180 minutes,*

KL *2000 mm to 4500 mm, and*

the hollow steel sections shall be Class 1, 2 or 3 in accordance with CAN/CSA-S16.1.

Table 1-Values of a

*Aggregate type**	*Circular columns*	*Square columns*
S	*0.075*	*0.065*
N	*0.085*	*0.075*

** Type S concrete is made with siliceous coarse aggregate; Type N concrete is made with carbonate coarse aggregate.*

For a selection of hollow structural sections produced in Canada, C_{max} *for concrete strengths of 30 MPa and 50 MPa may be read from Figures 1 to 6.*

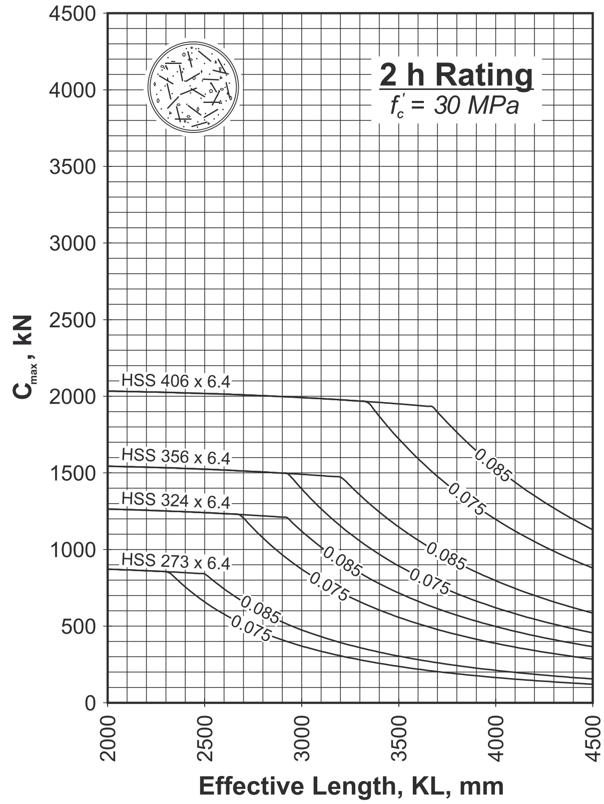

Figure 1: Round hollow steel columns with 30 MPa concrete and requiring a 2 h fire endurance period

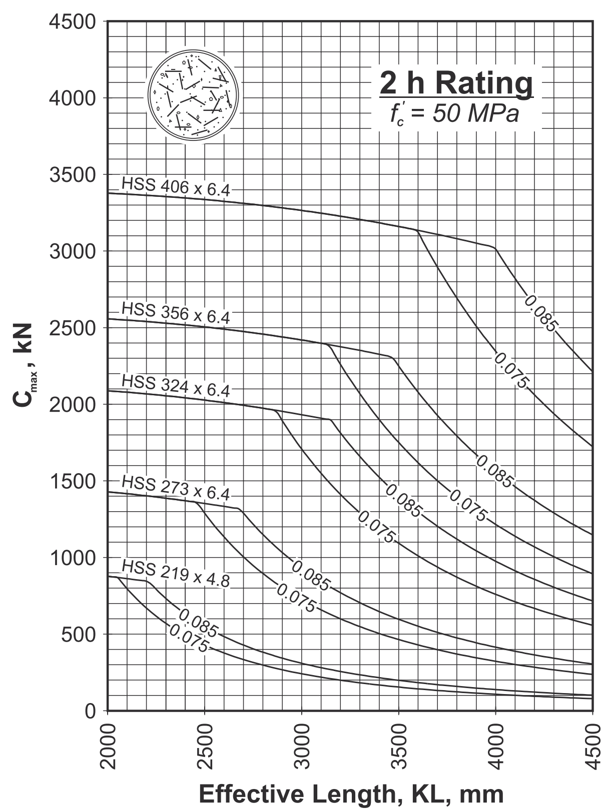

Figure 2: Round hollow steel columns with 50 MPa concrete and requiring a 2 h fire endurance period

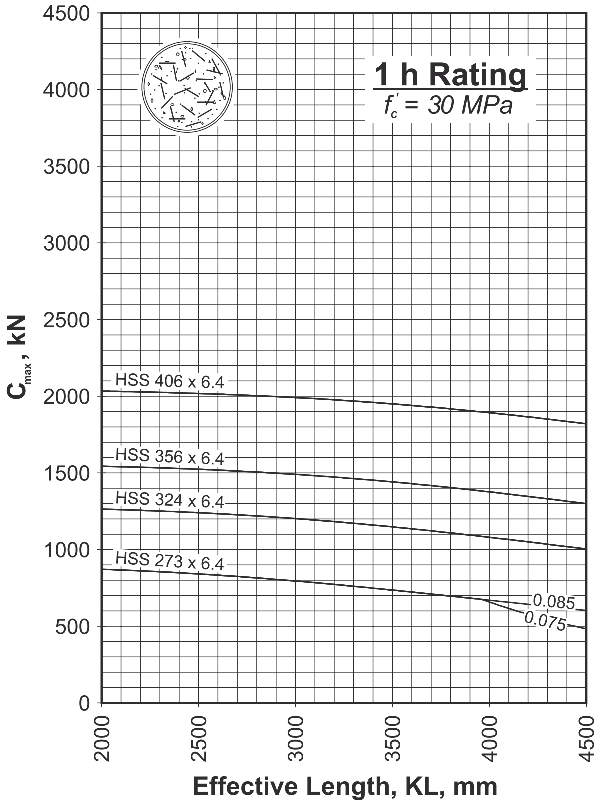

Figure 3: Round hollow steel columns with 30 MPa concrete and requiring a 1 h fire endurance period

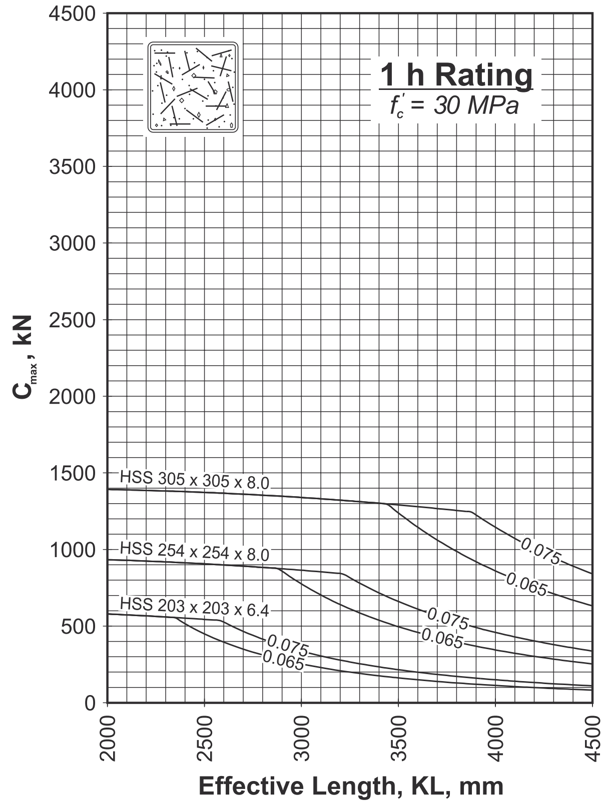

Figure 5: Square hollow steel columns with 30 MPa concrete and requiring a 1 h fire endurance period

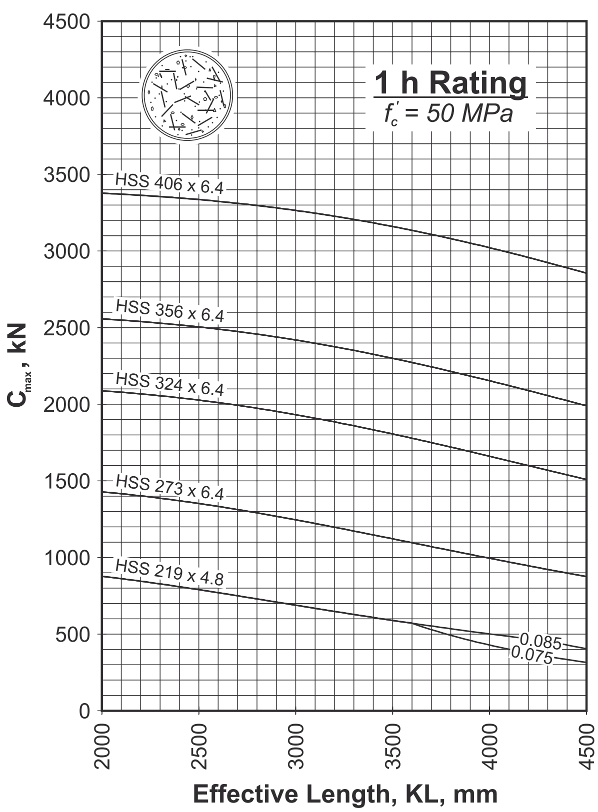

Figure 4: Round hollow steel columns with 50 MPa concrete and requiring a 1 h fire endurance period

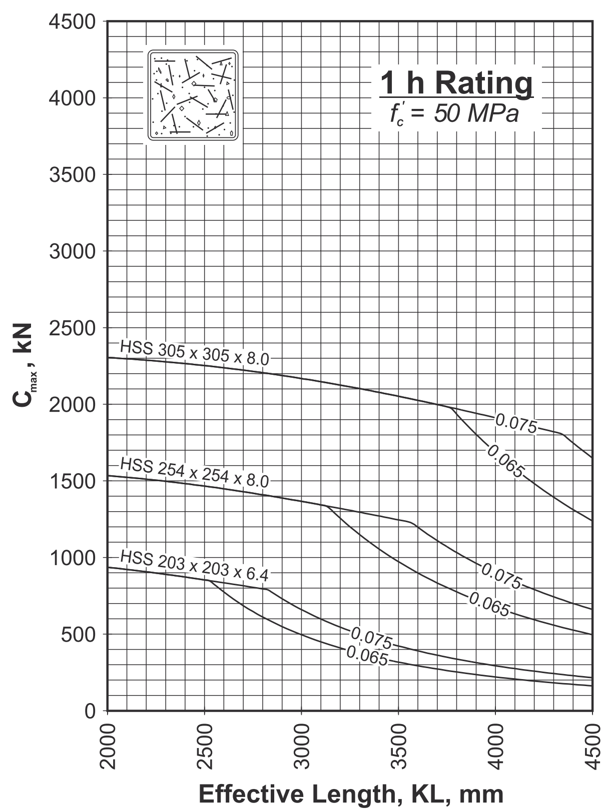

Figure 6: Square hollow steel columns with 50 MPa concrete and requiring a 1 h fire endurance period

COLUMN BEHAVIOUR

At room temperature, the axial load in the column is shared between the concrete core and steel section, and shifts primarily to the concrete core at elevated temperatures with the steel section providing confinement. Hence, it is important to provide direct bearing at the top and bottom of the column (9).

Factors which influence the fire endurance and load capacity of plain concrete-filled HSS columns include cross-sectional dimensions, length, concrete strength, and type of concrete aggregate. A general discussion of behaviour can be found in Fire Protection Bulletin #21.

With the addition of steel-fibre reinforcing, fire endurance ratings of up to 3 hours are possible. Much like the bar-reinforcing in the previous study, the steel fibres confine the concrete core by resisting the splitting forces generated as the concrete degrades and approaches its ultimate load carrying capacity.

Tests (1, 2) and comparisons with calculated fire endurance (5) showed that the fire endurance remains predictable and without sudden failure for loads up to 1.1 times the resistance of the unreinforced concrete core, $C_r^{'}$, and for effective column lengths up to 4500 mm.

At elevated temperatures, the moisture present in the concrete core turns to steam. A potential bursting hazard exists if the steam is not released into the atmosphere. To prevent catastrophic failure, vent holes as described in Note 3 must be provided.

Through-plate connections at intermediate floors, eccentric loading, HSS wall thickness and construction methods are discussed in reference 9.

DESIGN FORMULA

The simplified design formula, expressed in terms of a restricted column load for a desired fire-resistance rating, is given on page 2. The text is patterned after Article D-2.6.6. in the 1995 NBCC to convey the approach that will be proposed for the next NBCC. The design curves given on pages 2 and 3 were constructed using the proposed formula for a series of round and square hollow steel sections. The following notes apply:

Notes to Figures 1 through 6:

(1) $C_r^{'}$ is calculated in accordance with Clause 18.4 of CAN/CSA S16.1-94 (10) assuming normal-weight concrete, and S/T=0.25 where S is the short-term load on the column and T is the total load on the column. Confinement effects are ignored by setting $\tau = \tau^{'} = 1.0$.

(2) HSS designations and dimensions are in accordance with CAN/CSA-G312.3, and are given in the CISC Handbook of Steel Construction (11).

(3) Two unobstructed vent holes, each not less than 12.7 mm in diameter shall be provided at opposite ends of the column and at each intermediate floor to vent steam. The holes shall be located 150 mm from a base plate, cap plate or concrete slab. Pairs of holes should be orientated such that adjacent pairs are perpendicular (9).

REFERENCES

1. Kodur, V.K.R. and Lie, T.T., “Experimental Studies on the Fire Resistance of Circular Hollow Steel Columns Filled with Steel-Fibre-Reinforced Concrete”, IRC Internal Report No. 691, National Research Council of Canada, Institute for Research in Construction, Ottawa, Ontario, 1995.
2. Kodur, V.K.R. and Lie, T.T., “Experimental Studies on the Fire Resistance of Square Hollow Steel Columns Filled with Steel-Fibre-Reinforced Concrete”, IRC Internal Report No. 662, National Research Council of Canada, Institute for Research in Construction, Ottawa, Ontario, 1996.
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