BULLETIN No. 21

Fire Protection

CANADIAN STEEL CONSTRUCTION COUNCIL

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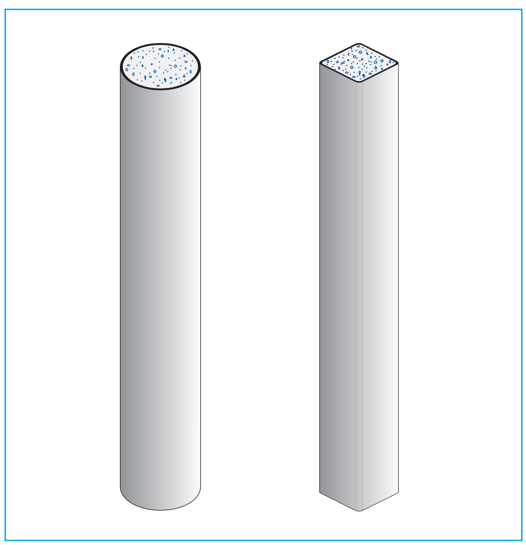
FIRE RESISTANCE OF PLAIN CONCRETE-FILLED STEEL HOLLOW STRUCTURAL SECTION COLUMNS

INTRODUCTION

In 1983, the National Research Council of Canada (NRCC), in a joint effort with the Canadian Steel Construction Council (CSCC), and with support from the American Iron and Steel Institute (AISI), initiated a comprehensive research programme studying the fire resistance of concrete filled steel hollow structural section (HSS) columns. Institute for Research in Construction (IRC) research staff and former CSCC Steel Fellows have since published a number of reports [References 2, 10, 12 and 13] describing the results of a large sample of loaded full scale tests and in-depth analytical studies. Meanwhile, research continued in Europe and resulted in several published articles [References 4 9].



TEST PROGRAMME

The work on HSS columns filled with plain concrete (i.e. without any reinforcing) was completed at NRCC in 1993. A report entitled =C1Assessment of the Fire Resistance of Steel Hollow Structural Section Columns Filled with Plain Concrete', co-authored by T. T. Lie and D. C. Stringer, was published as NRCC Report No. 644 in May 1993 [Reference 2]. In their report, the authors incorporated the published foreign test data as well as the results of 44 full scale columns tested at NRCC, and developed formulae for the calculation of fire resistance of circular and square columns filled with plain concrete that are suitable for incorporation into building codes. An article containing the content of Lie's and Stringer's report was published in the June 1994 issue of the Canadian Journal of Civil Engineering [Reference 1].

COLUMN BEHAVIOUR

At room temperature, both the steel section and the concrete core contribute to the total load carrying capacity of the composite column (i.e. C_{rc} C_r C'_r). Depending on the size of the steel section, concrete strength, etc., the core contributes from approximately 5% to 50% of the total column capacity i.e. $0.05\,C_{rc}$ C'_r $0.5\,C_{rc}$.

For circular columns of slenderness ratios within the practical range, the strength of the concrete core is also significantly enhanced due to the confinement provided by the steel tube. The benefit of this confinement effect is accounted for in

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CSCC

Algoma Steel Inc. Dofasco Inc. Ispat Sidbec Inc. Stelco Inc.
Canadian Fasteners Institute Canadian Institute of Steel Construction Canadian Sheet Steel Building Institute
Steel Service Centre Institute Corrugated Steel Pipe Institute Canadian Welding Bureau (Associate Member)

DESIGN FORMULA AND CURVES

A concrete-filled column's fire-resistance rating is a function of its size, slenderness ratio, the concrete strength and type as well as the load it is supporting (without load factors). To achieve a fire-resistance rating, a load restriction is usually required. This restricted column load can be calculated in accordance with the following new Article that will appear in the 1995 National Building Code of Canada:

Concentrically loaded hollow steel columns that are filled with plain 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 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 40 MPa,*

D *140 mm to 410 mm for round columns,*
140 mm to 305 mm for square columns,

R *≤ 120 minutes,*

KL *2000 mm to 4000 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	*0.07*	*0.06*
N	*0.08*	*0.07*

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

For hollow structural sections commonly available in Canada, C_{max} for concrete strengths of 30 MPa and 40 MPa may be read from Figures 1 to 6. For additional information on calculation procedures, as well as HSS nomenclature conventions, see Notes 1 and 2 on Page 4.

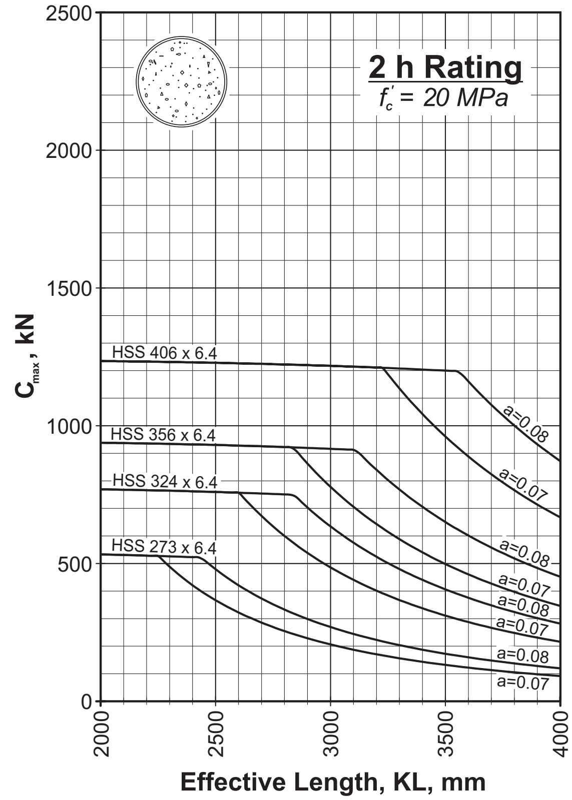

Figure 1: Round hollow steel columns with 20 MPa concrete and requiring a 2 h fire endurance period

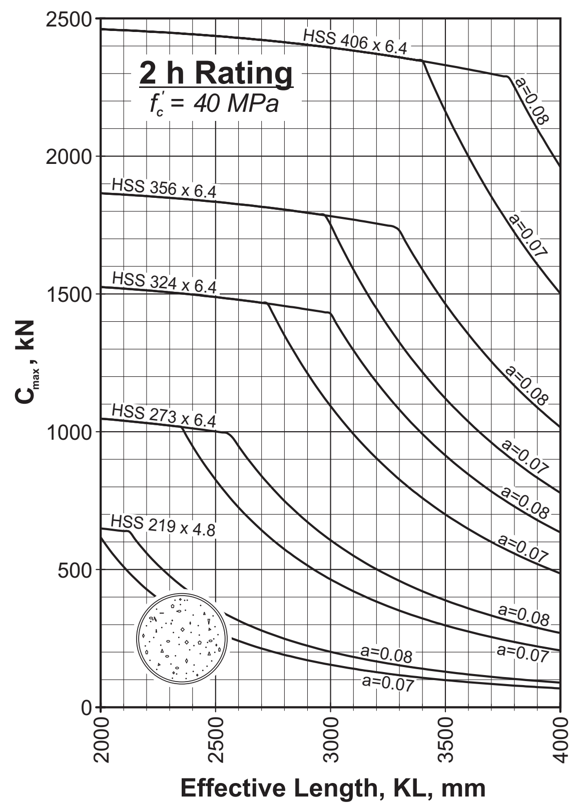

Figure 2: Round hollow steel columns with 40 MPa concrete and requiring a 2 h fire endurance period

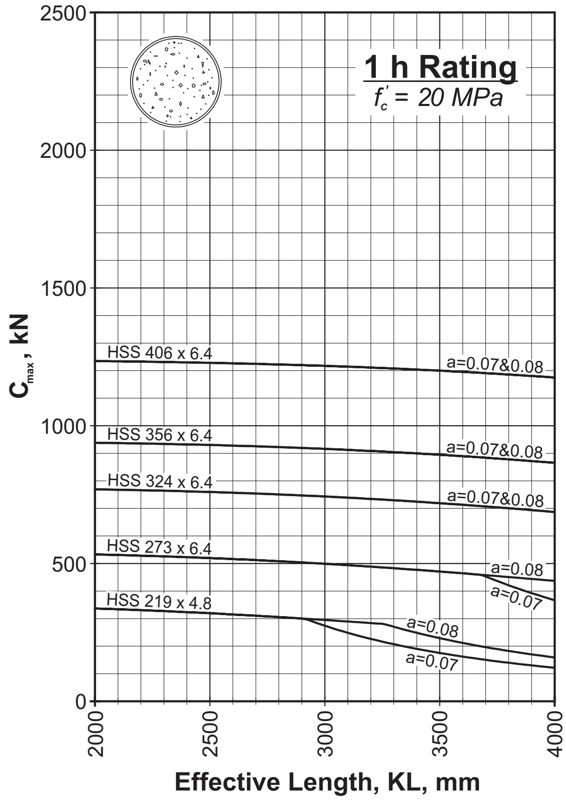

Figure 3: Round hollow steel columns with 20 MPa concrete and requiring a 1 h fire endurance period

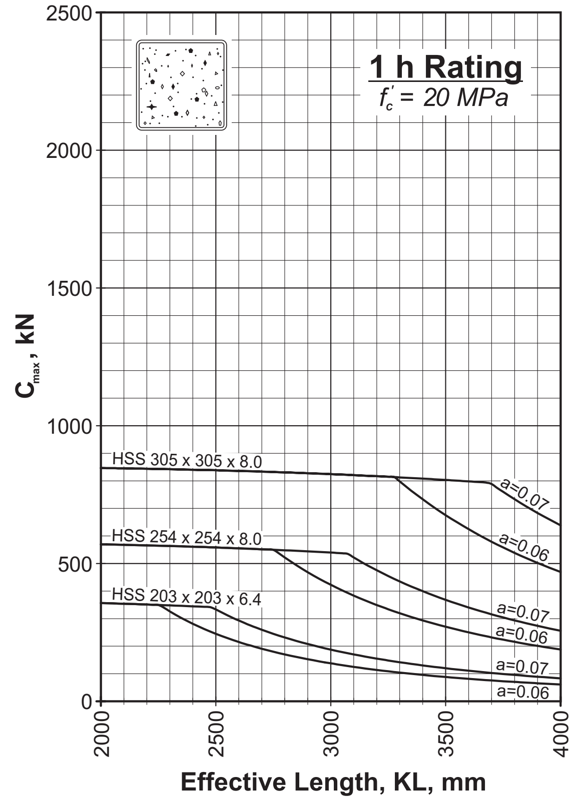

Figure 5: Square hollow steel columns with 20 MPa concrete and requiring a 1 h fire endurance period

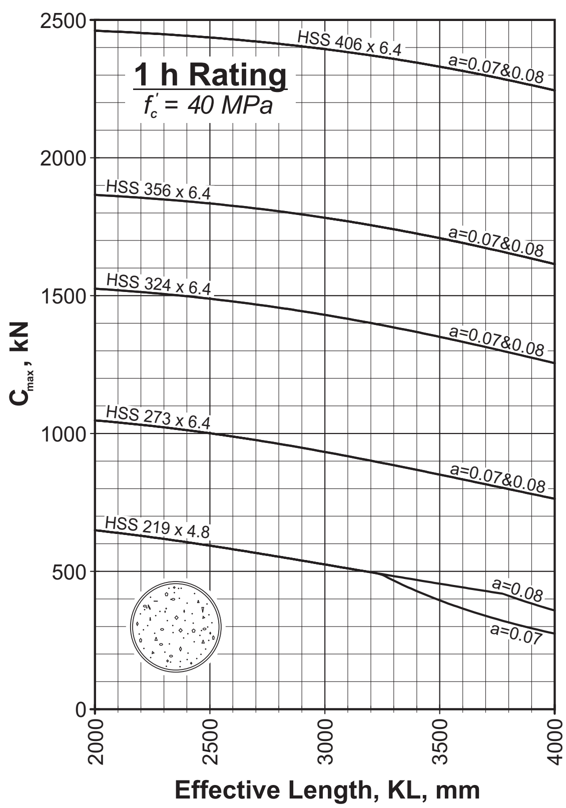

Figure 4: Round hollow steel columns with 40 MPa concrete and requiring a 1 h fire endurance period

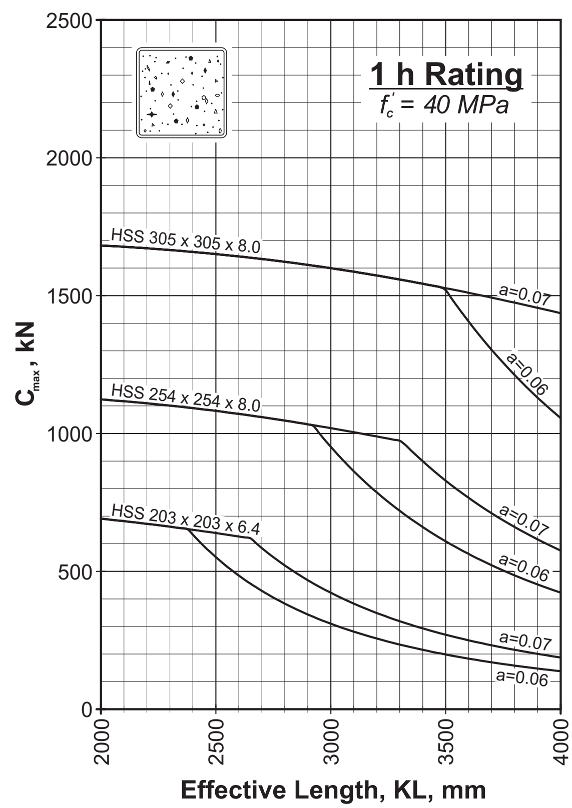

Figure 6: Square hollow steel columns with 40 MPa concrete and requiring a 1 h fire endurance period

CAN/CSA-S16.1 [Reference 14] by multiplying the resistance of the core (C_r') by an amplifier (τ').

As the temperature increases, the column begins to lose part of its strength because the steel's resistance reduces. However, the steel temperature rises more slowly than that of a column without any concrete fill because of the heat sink effect of the concrete core. This is referred to as a capacitive method of fire protection.

Lie et al found that slender columns lose their load carrying capacity faster than do stocky columns. The capacity of slender square columns can drop to well below the resistance of the concrete core alone, C_r'. Although stocky round columns can maintain their strength above C_r' (highest test load recorded $= 1.65\, C_r'$ [Reference 10]), occasions of sudden failure were observed in the test programme. Lie et al therefore restricted the loads for all columns to no greater than C_r', among other restrictions (see Page 2), to ensure a desirable and predictable behaviour. The beneficial confinement effect is also ignored by setting $\tau' = 1$.

Note 1:

In accordance with Clause 18.4 of CAN/CSA S16.1,

$$C_r' = 0.85\phi_c f_c' A_c \lambda_c^{-2}\left[\sqrt{1+0.25\lambda_c^{-4}} - 0.5\lambda_c^{-2}\right]$$

In which $\lambda_c = \dfrac{KL}{r_c}\sqrt{\dfrac{f_c'}{\pi^2 E_c}}$

ϕ_c = 0.60

r_c = radius of gyration of the concrete area, A_c

E_c = initial elastic modulus for concrete, considering the effects of long-term loading. For normal-weight concrete, with f_c' expressed in MPa, this may be taken as $\left(1+ S/T\right)2500\sqrt{f_c'}$, where S is the short-term load and T is the total load on the column. The column design curves on pages 2 and 3 have been derived based on $S/T = 0.25$.

Note 2:

In the curves on the preceding pages, and in accordance with CAN/CSA-G312.3, "Metric Dimensions for Structural Steel Shapes and Hollow Structural Sections", HSS 406 x 6.4 (for example) designates a round steel hollow structural section of 406 mm nominal outside diameter and 6.4 mm wall thickness, whereas HSS 305 x 305 x 8.0 designates a square hollow structural section of 305 mm nominal outside width and 8.0 mm wall thickness.

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