PART 5-5: Column with axial loads

P. Schaumann, T. Trautmann
University of Hannover, Germany

J. Žižka
Czech Technical University in Prague, Czech Republic

1 TASK

In the following example, a column of a department store will be dimensioned for fire resistance. The column is part of a braced frame and is connected bending resistant to the upper and lower column. The length is 3.0 m. During fire exposure, the buckling length can be reduced as seen below in Figure 1. The loads are centric axial compression forces. The column is exposed to fire on four sides. A hollow encasement of gypsum is chosen for fire protection. The required standard fire resistance class for the column is R 90.

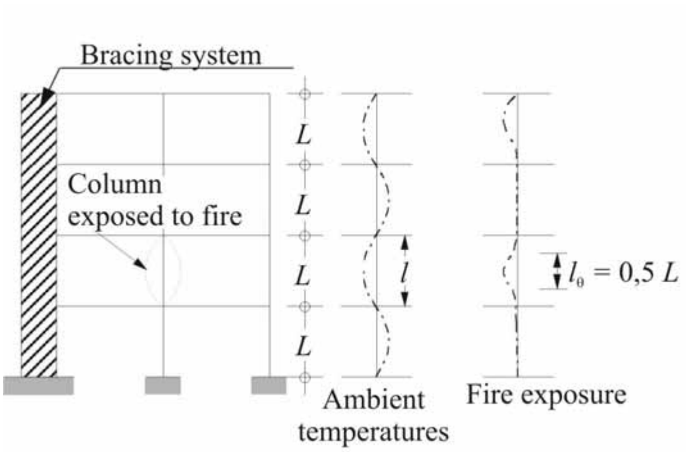

Figure 1. Buckling lengths of columns in braced frames

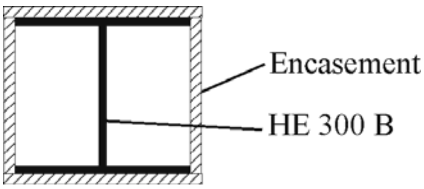

Figure 2. Cross-section of the column

Material properties:

Column:

Profile:	rolled section HE 300 B
Steel grade:	S 235
Cross-section class:	1

Yield stress: f_y = 23.5 kN/cm²
Cross-sectional area: A_a = 149 cm²
Elastic modulus: E_a = 21,000 kN/cm²
Moment of inertia: I_a = 8560 cm^4 (weak axis)

Encasement:
Material: gypsum
Thickness: d_p = 3.0 cm (hollow encasement)
Thermal conductivity: λ_p = 0.2 W/(m·K)
Specific heat: c_p = 1700 J/(kg·K)
Density: ρ_p = 945 kg/m³

Loads:
Permanent actions: G_k = 1200 kN
Variable actions: P_k = 600 kN

2 FIRE RESISTANCE OF COLUMN

2.1 *Mechanical actions during fire exposure*

EN 1991-1-2

The accidental situation is used for the combination of mechanical actions during fire exposure.

$$E_{dA} = E\left(\sum G_k + A_d + \sum \psi_{2,i} \cdot Q_{k,i}\right)$$

Section 4.3

The combination factor for department stores is $\psi_{2,1}$ = 0.6. So the axial load is determined to:

$$N_{fi,d} = 1200 + 0.6 \cdot 600 = 1560 \text{ kN}$$

2.2 *Calculation of the maximum steel temperature*

EN 1993-1-2

The analysis of EN 1993-1-2 is used to calculate the steel temperature of the hollow encased column. For a hollow encased member, the section factor is calculated to:

$$A_p/V = 2 \cdot (b+h)/A_a = 2 \cdot (30+30) \cdot 10^2/149 = 81 \text{ m}^{-1}$$

Section 4.2.5.2

By using the Euro-Nomogram (ECCS No.89), the maximal temperature $\theta_{a,max,90}$ of the steel bar is:

$$(A_p/V) \cdot (\lambda_p/d_p) = 81 \cdot 0.2/0.03 = 540 \text{ W/m}^3\text{K}$$

ECCS No.89

$$\Rightarrow \quad \theta_{a,max,90} \approx 445 \text{ °C}$$

2.3 *Verification in the temperature domain*

EN 1993-1-2

Within EN 1993-1-2 the verification in the temperature domain is notallowed for members in which stability phenomena have to be taken into account.

Section 4.2.4

2.4 *Verification in the strength domain*

The verification in the strength domain during fire exposure is carried out as a plastic ultimate state of the load-carrying capacity.

$$E_{fi,d,t} \le R_{fi,d,t}$$

Section 2.4.2

In this example, the verification has to be done with the axial forces.

$$N_{fi,d} \leq N_{b,fi,t,Rd}$$

The design resistance under high temperature conditions is calculated as:

$$N_{b,fi,t,Rd} = \chi_{fi} \cdot A_a \cdot k_{y,\theta,\max} \cdot \frac{f_y}{\gamma_{M,fi}}$$ Section 4.2.3.2

In dependence of $\theta_{a,max,90}$ the reduction factors $k_{y,\theta}$ and $k_{E,\theta}$ are given in Table 3.1 of the EN 1993-1-2. For intermediate values of the steel temperature, linear interpolation may be used.

$$\Rightarrow \quad k_{y,445°C} = 0.901$$ Section 3.2.1

$$k_{E,445°C} = 0.655$$

The load-carrying capacity is determined in consideration of the non-dimensional slenderness during fire exposure.

$$\bar{\lambda}_{fi,\theta} = \bar{\lambda} \cdot \sqrt{k_{y,\theta} / k_{E,\theta}} = 0.21 \cdot \sqrt{0.901/0.655} = 0.25$$ Section 4.2.3.2

where: EN 1993-1-1

$$\bar{\lambda} = L_{Kz} / (i_z \cdot \lambda_a) = (0.5 \cdot 300)/(7.58 \cdot 93.9) = 0.21$$ Section 6.3.1.3

With the non-dimensional slenderness the reduction factor for flexural buckling $\chi_{fi,\theta}$ can be calculated. EN 1993-1-2

$$\chi_{fi} = \frac{1}{\varphi_\theta + \sqrt{\varphi_\theta^2 - \bar{\lambda}_\theta^2}} = \frac{1}{0.61 + \sqrt{0.61^2 - 0.25^2}} = 0.86$$ Section 4.2.3.2

where:

$$\varphi = 0.5 \cdot \left[1 + \alpha \cdot \bar{\lambda} + \bar{\lambda}^2\right] = 0.5 \cdot \left[1 + 0.65 \cdot 0.25 + 0.25^2\right] = 0.61$$

and:

$$\alpha = 0.65 \cdot \sqrt{235/f_y} = 0.65 \cdot \sqrt{235/235} = 0.65$$

The design resistance arises to:

$$N_{b,fi,t,Rd} = 0.86 \cdot 149 \cdot 0.901 \cdot \frac{23.5}{1.0} = 2713 \text{ kN}$$

Verification:

$$N_{fi,d} / N_{b,fi,t,Rd} = 1560/2713 = 0.58 < 1 \qquad \checkmark$$

REFERENCES

ECCS No.89, *Euro-Nomogram*, Brussels: ECCS – Technical Committee 3 – Fire Safety of Steel Structures, 1995

EN 1991, *Eurocode 1:Actions on structures – Part 1-2: General actions – Actions on structures exposed to fire*, Brussels: CEN, November 2002

EN 1993, *Eurocode 3: Design of steel structures – Part 1-1: General rules*, Brussels: CEN, May 2005

EN 1993, *Eurocode 3: Design of steel structures – Part 1-2: General rules – Structural fire design*, Brussels: CEN, October 2006

QUALITY RECORD	WP5 DIF SEK		
Title	Example to EN 1994 Part 1-2: Composite beam		
Eurocode reference(s)	EN 1991-1-2:2005; EN 1993-1-2:2006; EN 1994-1-1:2004; EN 1994-1-2:2006		
ORIGINAL DOCUMENT			
	Name	**Company**	**Date**
Created by	P. Schaumann	Univ.of Hannover	24/11/2005
	T. Trautmann	Univ.of Hannover	24/11/2005
Technical content checked by	M. Haller	ArcelorMittal	24/11/2005
TRANSLATED DOCUMENT			
Translation made and checked by:	J. Chlouba	CTU in Prague	10/01/2008
Translated resource approved by:	Z. Sokol	CTU in Prague	25/01/2008
National technical contact:	F. Wald	CTU in Prague	