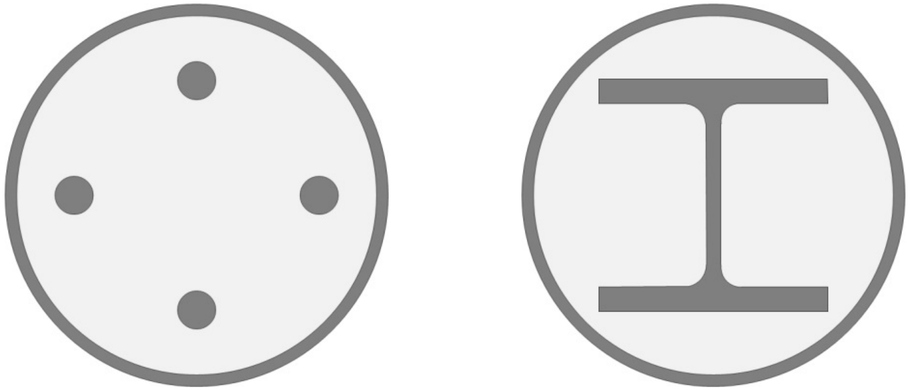
Institute for Steel Construction
Prof. Peter Schaumann

Proposal for the improvement of EN 1994-1-2: Structural behaviour of composite columns (simple calculation model)



W. Weisheim

Introduction

- Simplified design method for concrete filled tubular (CFT) columns: EN 1994-1-2 Clause No. 4.3.5.1 / Annex H

$$(EI)_{fi,eff} = \sum(\phi_{a,\theta} \cdot E_{a,\theta} \cdot I_{a,\theta}) + \sum(\phi_{s,\theta} \cdot E_{s,\theta} \cdot I_{s,\theta}) + \sum(\phi_{c,sec,\theta} \cdot E_{c,\theta} \cdot I_{c,\theta})$$

- **Reasons for the improvement:**
  - “unsafe” results for fire resistance ($\lambda > 0.5$) acc. Zhao (2010) and Espinós et al. (2010)
  - No definition of reduction coefficients; if equal to unity: neglect the effect of thermal stresses
  - No method for the determination of the cross-section temperature


EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 1994-1-2

August 2005

ICS 13.220.50; 91.010.30; 91.080.10; 91.080.40

Supersedes ENV 1994-1-2:1994
Incorporating corrigendum July 2008

English Version

Eurocode 4 - Design of composite steel and concrete structures - Part 1-2: General rules - Structural fire design

Eurocode 4 - Calcul des structures mixtes acier-béton - Partie 1-2: Règles générales - Calcul du comportement au feu

Eurocode 4 - Bemessung und Konstruktion von Verbundtragwerken aus Stahl und Beton - Teil 1-2: Allgemeine Regeln Tragwerksbemessung im Brandfall

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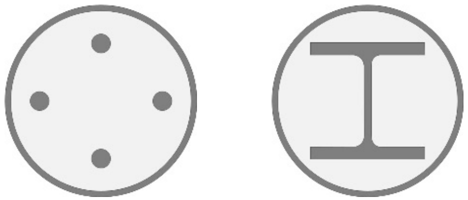
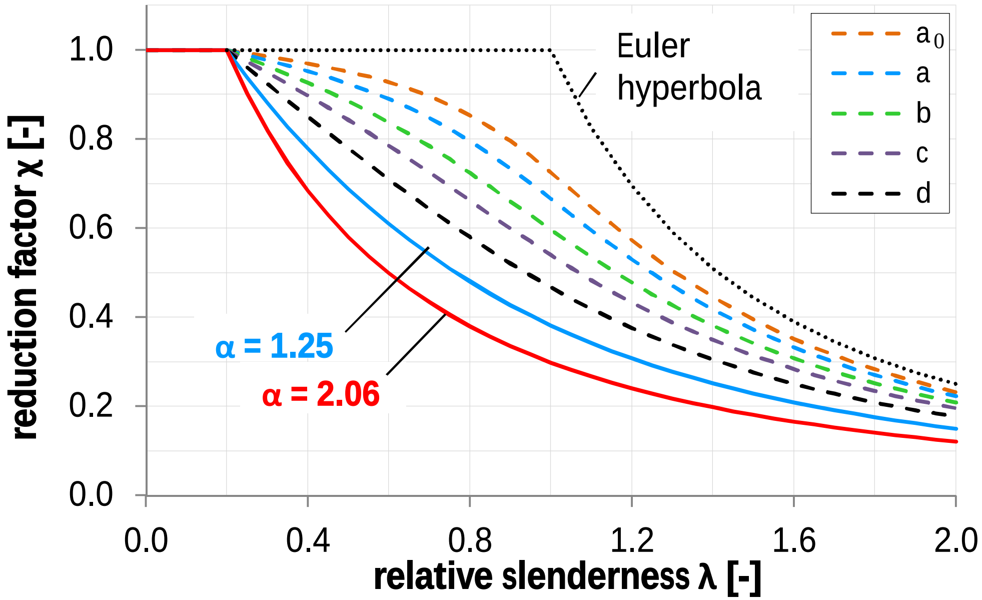
Ref. No. EN 1994-1-2:2005: E

Simplified Calculation Method (1)

- **Proposal**: Alternative approach by Bergmann (2013)
- Method for CFT columns with and without I-section profiles
- Self-contained procedure (thermal + mechanical)
- Based on equivalent beam method (European buckling curves)
- Two additional buckling curves (α = 1.25; α = 2.06) introduced
- Based on numerical parameter studies





Simplified Calculation Method (2)

- **Limitations**:
  - Centric load
  - Concrete strength class: C 20/25 – C 50/55
  - Outer tube diameter: $200 \leq D_a \leq 1000$ mm
  - Tube thickness: $3 \leq t_a \leq 10$ mm
  - Flame exposure period: 30, 60, 90 minutes (standard fire resistance R30, R60, R90 acc. to ISO 834)
- **Simplified temperature calculation**:
  - Steel tube temperature:

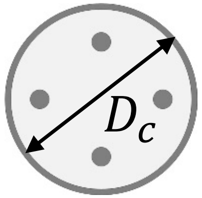
$$\theta_a = \theta_{ISO\ 834}\ (°C)$$

Standard Fire Resistance (SFR)	θ_a (°C)
R30	842
R60	945
R90	1006

Simplified Calculation Method (3)

- Concrete temperature:

$$\theta_{c,m} = a_1 \cdot \frac{1}{\sqrt{D_c}} + a_2 \quad (°C)$$



SFR	a_1 (°Cm$^{1/2}$)	a_2 (°C)
R30	262.48	-62.22
R60	343.31	-68.39
R90	388.65	-55.76

- Temperature calculation for the reinforcement and the embedded I-section profile analogous

- **Temperature reduced axial plastic resistance**:
  - Analogous to EN 1994-1-2; temperature gradient along the concrete:

$$N_{fi,pl,Rd} = \sum(A_{a,\theta} \cdot f_{ay,\theta})/\gamma_{M,fi,a} + \sum(A_{s,\theta} \cdot f_{sy,\theta})/\gamma_{M,fi,s} + \sum(A_{c,\theta} \cdot f_{c,\theta})/\gamma_{M,fi,c}$$

$$f_{c,\theta} = k_{f,c,\theta} \cdot f_c$$

$$k_{f,c,\theta} = 1{,}0 - \frac{a_6}{D_c}$$

Simplified Calculation Method (4)

- **Effective bending stiffness in fire**:
  - Dependent on time of flame exposure:

$$(EI)_{fi,eff} = \phi \cdot (E_{a,\theta} \cdot I_a + E_{s,\theta} \cdot I_s + 1.8 \cdot E_{c,sec,\theta} \cdot I_c)$$

SFR	R30	R60	R90
ϕ	0.85	0.85	0.90

- **Axial resistance in fire**:
  - According to the equivalent beam method from the room-temperature design of EN 1993-1-1:

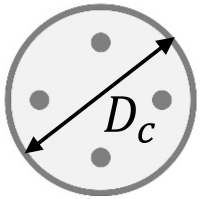
$$N_{fi,Rd} = \chi \cdot N_{fi,pl,Rd} \qquad \bar{\lambda}_\theta = \sqrt{\frac{N_{fi,pl,Rd}}{N_{fi,cr}}} \qquad N_{fi,cr} = \frac{\pi^2 \cdot (EI)_{fi,eff}}{l_\theta^2}$$

$$\chi = \frac{1}{\phi^2 + \sqrt{\phi^2 - \bar{\lambda}_\theta^{\,2}}}$$

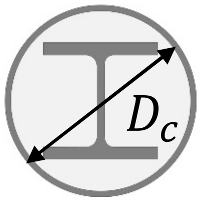
Simplified Calculation Method (5)

- Allocation of the cross-section to the buckling curves is oriented by the outer concrete diameter D_c:

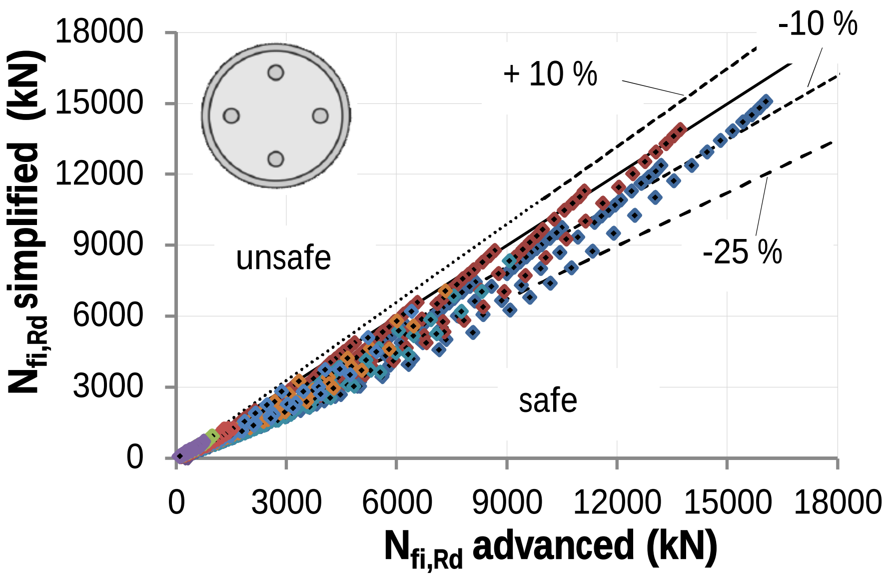
SFR	R30	R60	R90
180 ≤D_c<280	d	α=1.25	α=2.06
280 ≤D_c<380	c	c	d
380 ≤D_c<580	b	b	b
580 ≤D_c	a	a	a

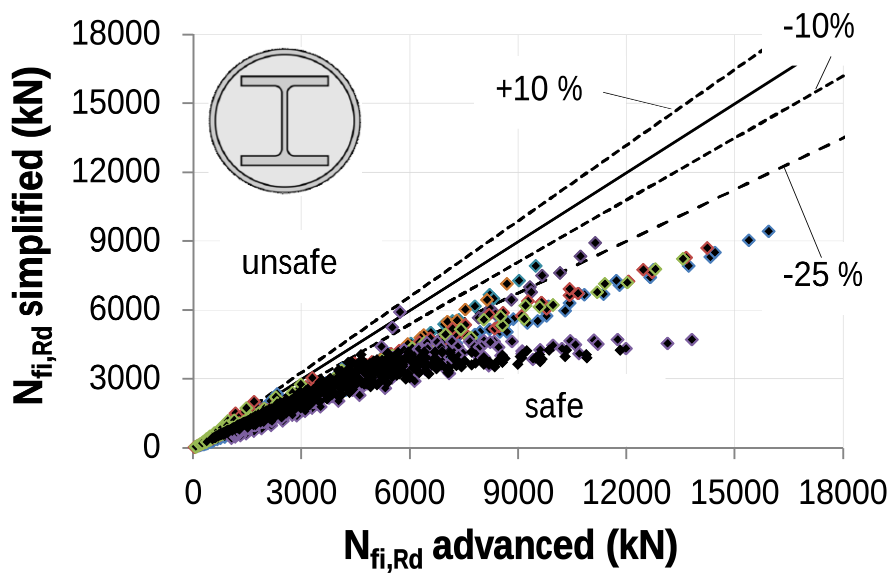


SFR	R30	R60	R90
180 ≤D_c<230	d	α=1.25	α=2.06
230 ≤D_c<280	c	d	α=1.25
280 ≤D_c<380	b	c	d
380 ≤D_c<480	b	c	c
480 ≤D_c<680	b	b	b
680 ≤D_c	a	a	a



Evaluation of the Method





- Verification of Bergmann method by comparing calculated load-bearing capacities with advanced numerical model results
- Simplified calculation method leads to reliable but partially very conservative results

References

[1] Bergmann, M.: Zur Bemessung von Hohlprofilverbundstützen im Brandfall (*Design of composite hollow- section columns in fire*), Institut für Konstruktiven Ingenieurbau, Bergische Universität Wuppertal, Diss. 2013.

[2] CEN. EN 1994-1-2, Eurocode 4: Design of composite steel and concrete structures. Part 1-2: General rules – Structural fire design. Brussels, Belgium: Comité Européen de Normalisation; 2005.

[3] CEN. EN 1993-1-1, Eurocode 3: Design of steel structures. Part 1-1: General rules and rules for buildings. Brussels, Belgium: Comité Européen de Normalisation; 2005.

[4] Zhao B., Slenderness limit for composite columns with concrete filled hollow sections under fire situation. Centre Technique Industriel de la Construction Métallique (CTICM), France 2010.

[5] Espinós A., Romero M.L., Research Report: Fire Resistance of Concrete Filled Tubular Columns. EN 1994-1-2 Simple Calculation Model Revision. Universidad Politecnica de Valencia, Spain 2010.

Thank you for your interest!