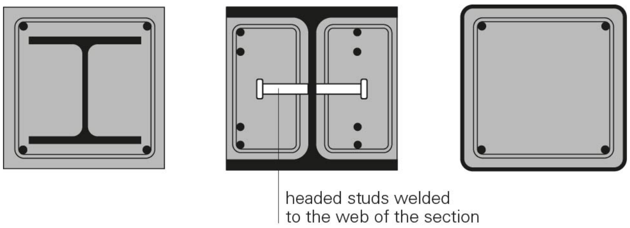
## 4.5 Fire limit state

EN 1994-1-2 considers the fire load case for three types of composite columns (fig. 4.19):
– fully encased steel sections;
– partially encased steel sections;
– hollow sections filled with unreinforced or reinforced concrete.




*4.19 The three types of composite column covered by EN 1994-1-2 provides a design method in the case of fire.*

The assessment methods in EN 1994-1-2 have three levels of complexity:
– design tables;
– simple calculation models;
– advanced calculation models.

A starting point for the design tables and simple calculation models is that a constant temperature is assumed over the entire length of the column. The relationships between the temperature and the material properties for steel and concrete are considered in Composite structures 2, section 2.8.1, see also EN 1994-1-2, chapter 3.
An explanation of the background to the simple calculation models is given below. Then, for each of the three types of column within the scope defined above, the first two approaches are discussed, namely design tables and simple calculation models. For information on the contents of EN 1994-1-2 reference is made to Composite structures 1, where design considerations, basic assumptions and execution aspects are also covered.

### 4.5.1 Simple calculation models

The simple models in EN 1994-1-2 may only be used for columns in braced frames, to determine resistance when the column is heated homogeneously according to the standard fire curve. The model for determining the design value of the fire resistance of an axially loaded column is divided into two independent steps:

- Step 1. Calculate the temperature-field in the composite cross-section after exposure to a fire using a heat flow calculation. Software is generally required for this step.
- Step 2. Calculate the design value for the axial buckling load $N_{fi,Rd}$ for the temperatures obtained from step 1.

The design value of the axial compression force is determined from:

$$N_{fi,Rd} = \chi N_{fi,pl,Rd} \tag{4.29}$$

Here $\chi$ is the reduction factor according to curve c from EN 1993-1-1, cl. 6.3.1, see also Structural basics 6 (Assessment by code checking), figure 6.47. This factor depends on the relative slenderness of the column in a fire situation.

$$\bar{\lambda}_\theta = \sqrt{\frac{N_{fi,pl,Rd}}{N_{fi,cr}}} \tag{4.30}$$

For the design value of the plastic resistance in a fire situation, $N_{fi,pl,Rd}$ can be used:

$$N_{fi,pl,Rd} = \sum_j \frac{A_{a,\theta} f_{ay,\theta}}{\gamma_{M,fi,a}} + \sum_k \frac{A_{s,\theta} f_{sy,\theta}}{\gamma_{M,fi,s}} + \sum_m \frac{A_{c,\theta} f_{cy,\theta}}{\gamma_{M,fi,c}} \tag{4.31}$$

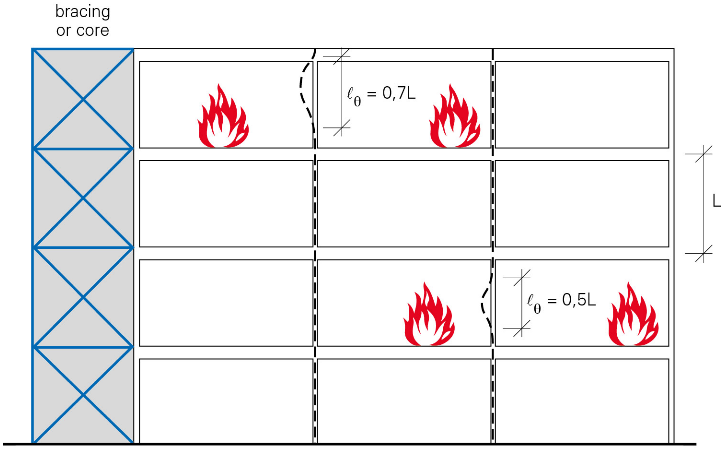
The Euler buckling force $N_{fi,cr}$ – the elastic critical load – in a fire situation follows from:

$$N_{fi,cr} = \frac{\pi^2 (EI)_{fi,eff}}{\ell_\theta^2} \tag{4.32}$$

For the effective flexural stiffness $(EI)_{fi,eff}$ in case of fire, normal temperature values are reduced by a factor $\varphi_{i,\theta}$, which accounts for the effect of thermal stresses:

$$(EI)_{fi,eff} = \sum_j \left(\varphi_{a,\theta} E_{a,\theta} I_{a,\theta}\right) + \sum_k \left(\varphi_{s,\theta} E_{s,\theta} I_{s,\theta}\right) + \sum_m \left(\varphi_{c,\theta} E_{c,sec,\theta} I_{c,\theta}\right) \tag{4.33}$$

Figure 4.20 indicates the buckling lengths of the columns. A column length which is continuously connected to the columns above and below (totally rigid and/or full strength), may be considered as fully restrained. This assumption may be made on the condition that the fire resistance of the separating floors is at least equal to the fire resistance of the columns.

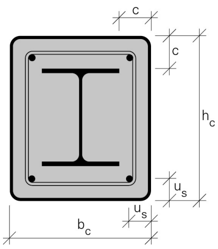



*4.20 Buckling length of columns in the fire situation.*

### 4.5.2 Fully encased steel sections

The assessment method in section 4.5.1 applies to fully encased steel sections. EN 1994-1-2 also contains design tables for fully encased steel sections used in a braced frame, see table 4.21 (in EN 1994-1-2, table 4.4) and 4.22 (in EN 1994-1-2, table 4.5). The maximum length of a column may be up to thirty times the minimum external dimension of its cross-section.
Both tables give minimum values for the external dimensions of the column, and the concrete cover with respect to the reinforcing steel and/or the steel section for various fire resistances. A basic assumption is that the steel does not reach such a high temperature that the material properties must be reduced. The fire resistance given in the tables is achieved for all load levels $\eta_{fi,t}$.
Table 4.21 and 4.22 apply to both centrically and eccentrically loaded columns, although when determining $R_d$ the eccentricity of the load should clearly be taken into account. Table 4.22 applies when the contribution of the concrete has not been taken into account in the assessment of the column at normal temperature: the concrete then only provides an insulating function.
With the indicated concrete cover c to the steel section, a fire resistance R30 to R180 is achieved. In a note to table 4.5 of EN 1994-1-2 is siated that in order to achieve R30 the concrete only needs to be placed between the flanges.

*4.21 Minimum values (achieved for all load levels) for the cross-section and the concrete cover of (rectangular) composite columns, comprising fully encased steel sections. Choice of two alternative solutions 1 and 2.*

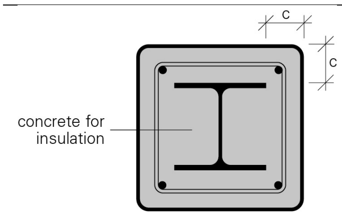



| | | standard fire resistance | | | | | |
|---|---|---|---|---|---|---|---|
| | | R30 | R60 | R90 | R120 | R180 | R240 |
| | cross-sectional dimensions $h_c$ and $b_c$ (mm)[a] | 150 | 180 | 220 | 300 | 350 | 400 |
| 1 | cover on steel section c (mm) | 40 | 50 | 50 | 75 | 75 | 75 |
| | cover to centre of reinforcement $u_s$ (mm) | 20[b] | 30 | 30 | 40 | 50 | 50 |
| | cross-sectional dimensions $h_c$ and $b_c$ (mm)[a] | – | 200 | 250 | 350 | 400 | – |
| 2 | cover on steel section c (mm) | – | 40 | 40 | 50 | 60 | – |
| | cover to centre of reinforcement $u_s$ (mm) | – | 20[b] | 20[b] | 30 | 40 | – |

a. According to the authors, this table is also valid for rectangular cross-sections, as long as the minimum values of $h_c$ and $h_b$ are used.

b. These values have to be assessed according to EN 1992-1-2, cl. 4.4.1.2.

*4.22 Minimum concrete cover for a steel section with concrete used simply as insulation.*




| | standard fire resistance | | | | |
|---|---|---|---|---|---|
| | R30 | R60 | R90 | R120 | R180 |
| cover on steel section c (mm) | 0 | 25 | 30 | 40 | 50 |

### 4.5.3 Partially encased steel sections

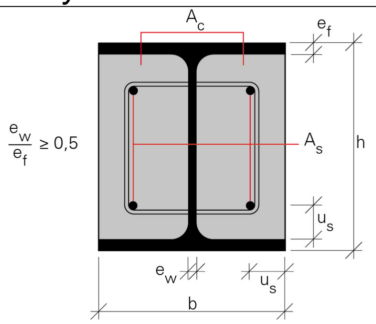
For partially encased steel sections, design table 4.6 in EN 1994-1-2, cl. 4.2.3.3 can be used. A simple calculation model is described in appendix G.

*Design table*

The design table in EN 1994-1-2 (reproduced below as table 4.23) shows the minimum dimensions for which a certain load level can be achieved. For the determination of $R_{fi,d,t} = \eta_{fi,t}R_d$ reinforcement

percentages greater than 6% and less than 1% may not be taken into account. The table may be applied for structural steel with grades S235, S275, and S355.
In determining $\eta_{fi,t}$, $R_d$ should be based on twice the buckling length used for fire calculations. The remaining requirements are the same as for table 4.21, as described in section 4.5.2.

*4.23 Minimum values for the cross-section dimensions, the concrete cover to the centre of the reinforcement, and the reinforcement ratio of (rectangular) composite columns, comprising partially encased steel sections.*




| load level | | standard fire resistance R30 | R60 | R90 | R120 |
|---|---|---|---|---|---|
| $\eta_{fi,t} \leq 0{,}28$ | cross-sectional dimensions h and b (mm)[a] | 160 | 200 | 300 | 400 |
| | cover to centre of reinforcement $u_s$ (mm) | – | 50 | 50 | 70 |
| | reinforcement ratio $A_s/(A_c + A_s)$ (%) | – | 4 | 3 | 4 |
| $\eta_{fi,t} \leq 0{,}47$ | cross-sectional dimensions h and b (mm)[a] | 160 | 300 | 400 | – |
| | cover to centre of reinforcement $u_s$ (mm) | – | 50 | 70 | – |
| | reinforcement ratio $A_s/(A_c + A_s)$ (%) | – | 4 | 4 | – |
| $\eta_{fi,t} \leq 0{,}66$ | cross-sectional dimensions h and b (mm)[a] | 160 | 400 | – | – |
| | cover to centre of reinforcement $u_s$ (mm) | 40 | 70 | – | – |
| | reinforcement ratio $A_s/(A_c + A_s)$ (%) | 1 | 4 | – | – |

a. According to the authors, this table is also valid for rectangular cross-sections, as long as the minimum values of $h_c$ and $h_b$ are used.