Basic principles

Composite girders and composite columns are verified with regards fire protection by classifying them in accordance with DIN 4102 – Section 7. The standard contains tables for

- concrete-filled composite hollow sections
- composite columns made of
  - concrete-filled hollow sections
  - steel girders fully encased in concrete
  - steel sections partially encased in concrete

using commercially available rolled sections according to DIN EN 10025 or welded sections, concrete grades > C25, reinforcing steel BSt 500 S.

Concrete-filled composite hollow sections

in accordance with the ‘Guidelines for Dimensioning and Executing Steel Composite Girders’ can be classified in the fire resistance classes R30 to R180-A according to DIN 4102 depending on the utilisation grade provided the requirements for minimum cross-section dimensions and amount of reinforcement are satisfied. The girder has to be protected against fire from above, especially when composite decks (trapezoidal sheeting) are used. Decks made of reinforced concrete or composite decks with building inspectorate approval in the required fire resistance class protect the crown of the steel support adequately.

![Fig. 1: System and loading](image)

The dimensioning tables are valid for a statically determinate supported structure and for the regions of positive moments for statically indeterminate composite girders. For verification in accordance with Table 1, additional requirements have to be satisfied when dimensioning the shear reinforcement. The values in the table were determined for steel girders of steel grade S355. For S235 the reinforcement required may be reduced to 70%. The additional reinforcement is pure reinforcement for fire protection. The concrete has to be connected tightly to the section using brackets, hooks or shear connectors.

### Table 1: Minimum cross-section dimensions \( \min b \) and required ratio \( \min (A_s/A_{Fl}) \) of additional reinforcement of lower flange area for concrete-filled composite hollow sections

<table>
<thead>
<tr>
<th>Line</th>
<th>Prerequisites</th>
<th>Fire Resistance Classification-Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>( b/s \geq 18; \ t/s \leq 2 )</td>
<td>R 30-A</td>
</tr>
<tr>
<td>1.1</td>
<td>( \text{Slab thickness } d \geq 15 \text{cm} )</td>
<td>70/0.0</td>
</tr>
<tr>
<td>1.2</td>
<td>( \text{Reinforcement ratio of concrete core } \leq 0.05 )</td>
<td>60/0.0</td>
</tr>
<tr>
<td>1.3</td>
<td>( \text{Concrete grade } \geq C25 )</td>
<td>60/0.0</td>
</tr>
<tr>
<td>2</td>
<td>( \text{Utilisation factor } \alpha_s = 0.4 )</td>
<td>80/0.0</td>
</tr>
<tr>
<td>2.1</td>
<td>( \text{Minimum width } \min b \text{ in mm/min } (A_s/A_{Fl}) )</td>
<td>80/0.0</td>
</tr>
<tr>
<td>2.2</td>
<td>( \text{corresponding section height } h \geq 0.9 \times \min b )</td>
<td>70/0.0</td>
</tr>
<tr>
<td>2.3</td>
<td>( \text{corresponding section height } h \geq 1.5 \times \min b )</td>
<td>60/0.0</td>
</tr>
<tr>
<td>2.4</td>
<td>( \text{corresponding section height } h \geq 3.0 \times \min b )</td>
<td>-</td>
</tr>
</tbody>
</table>

*) Allowances for reinforcement steel Bst 500 S

Line

1
1.1
1.2
1.3
2
2.1
2.2
2.3
2.4
Example of structural fire design using tables for a composite girder

The fire resistance class of a composite girder in HEA 500, S235 is determined according to Table 1. The reinforced concrete deck in C35 has a thickness of d = 18 cm and a width of 5 m. The existing moment is exist \( M = 767.3 \) KNm.

In order to use Table 1, various constraints have to be satisfied.

HEA 500: 
- exist \( b/s = 300/12 = 25 > 18 \)
- exist \( t/s = 23/12 = 1.92 < 2 \)

Concrete slab: 
- \( d = 18 \) cm > 15
- \( C_{35} > C_{25} \)

To determine the utilisation factor \( \alpha_5 \), the plastic load capacity limit is determined in accordance with 'Guidelines for Steel Composite Girders (3.81)': \( M_{pl} = 1856.9 \) KNm

\[
\alpha_5 = \frac{\text{exist}M}{M_{pl}} = \frac{767.3}{1856.9/1.7} = 0.70
\]

Classification is in accordance with Line 2.2 for the fire resistance class R 120-A:

With a section height \( h = 490 > 1.5 \cdot 300 = 450 \) and flange width \( b = 300 \) mm, this gives req \( A_e/A_{fl} = 0.4 \).

The required reinforcement \( A_e \) may be reduced to 70% because of the use of steel grade S235.

req \( A_e = 0.7 \cdot 0.4 \cdot A_{fl} = 19.32 \) cm²

Selected: 2 bars per chamber \( 4 \) Ø 25,

\( A_s = 4 \cdot 4.91 = 19.6 \) cm² \( > 19.32 \) cm²

Minimum spacing for tensile reinforcement \( u = 70 \) mm, \( u_s = 60 \) mm

The reinforcement ratio of the concrete block must not exceed 0.05: check of the amount of reinforcement of the concrete block:

\( A_e/A_{bo} = 19.6 / (49 \cdot 30-198) = 0.015 < 0.05 \)

Composite columns

Composite columns in accordance with DIN 18806 Part 1 with four-sided exposure to flames are classified according to DIN 4102-4. They must have the specified minimum cross-section dimensions depending on the utilisation factor \( \alpha_6 \).

The prerequisite for use is that the rotation of the columns is obstructed effectively in the fire situation. If the girders are connected using cleats or carried out continuously over several storeys using a spliced connection (examples: DIN 4102-4 Figs. 72 to 74), one can assume effective clamping of the final cross-sections in stiffened support systems. The utilisation factor \( \alpha_6 \) is the ratio of the 1.0-fold design load to the calculated 1/\( \gamma \)-fold loading capacity.

Composite columns made of concrete-filled hollow sections

The tables are valid for rectangular and round hollow sections with \( D/s \) or \( d/s \geq 25 \), S235 and use of a concrete grade \( \geq C_{25} \) and Bst 500 S as reinforcement. Provision should be made for at least four longitudinal reinforcement bars which are fixed in position during concreting by means of appropriate lateral ties. The hollow sections must have two holes (\( A \geq 6 \) cm²) as openings for vapour at a spacing of maximum 5 m and at the column ends.

Composite columns made of steel sections fully encased in concrete

This type of composite column fulfils the requirements for the fire resistance rating at full load utilisation if the minimum cross-section dimensions are satisfied.

Composite columns made of steel sections partially encased in concrete

Hollow composite columns filled with concrete achieve fire resistance ratings up to R 60 without a load reduction. The minimum thicknesses \( d \) and \( b \), the corresponding minimum spacing \( u \) of the longitudinal reinforcement and the necessary ratio of the web-to-flange thickness as a function of the utilisation factor are given in Table 2. Lower demands apply to composite columns with a column length \( \leq 7.50 \) m and a minimum reinforcement ratio of 3%.
The concrete has to be secured against falling out and connected to the column web via a welded-on brackets, hooks or shear connectors. The spacing of the fasteners must not be greater than 500 mm and approx. 100 mm in the node area. The fixing of the brackets required by DIN 18806 Part 1 may be considered for the anchoring needed in the fire situation.

<table>
<thead>
<tr>
<th>Line</th>
<th>Utilisation factor $\alpha_5 = 0.4$</th>
<th>Minimum thicknesses b and d in mm</th>
<th>Minimum spacing u</th>
<th>Minimum ratio s/t</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>R 30-A</td>
<td>R 60-A</td>
<td>R 90-A</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>160</td>
<td>260</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40</td>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.6</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>2</td>
<td>Utilisation factor $\alpha_5 = 0.7$</td>
<td></td>
<td>200</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>35</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.6</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Table 2: Minimum cross-section dimensions for composite columns made of steel sections partially encased in concrete

Example of structural fire design using tables for a composite column web partially encased in concrete

A column hinged at both ends with a length $l = 8.0 \text{m}$ is subjected to an axial force $N = 1400 \text{KN}$. The supporting system is braced on the surface of the wall ($z$-axis). The column is subjected to a buckling load along the strong $y$-axis.

Composite columns in HEB 340, S 235
Concrete C 25
Reinforcing steel BSt 500 S, 4 Ø 20 mm, $u = 50 \text{mm}$
Fire protection requirement R 90

The calculated load capacity of the composite columns with a buckling length Sky = 8.0 m (buckling load about y-axis) is determined according to DIN 18806.

$N_{pl} = 5822 \text{KN}$;
$N_{ki} = 13533 \text{KN}$; $\bar{\lambda} = 0.655$; $\kappa = 0.817$

Utilisation factor $\alpha = \frac{\gamma \times N_{pl/y}}{\kappa \times N_{ki}} = 0.4$
Classification is carried out in accordance with Table 2, Line 1: Minimum cross-section dimensions:

- $b = 300 = \text{min } b = 300 \text{ mm}$
- $d = 340 > \text{min } d = 300 \text{ mm}$

Minimum spacing of the longitudinal reinforcement $u = 50 \text{ mm}$, minimum ratio web / flange thickness $e_x / t = 0.56 > \text{req } e_x / t = 0.5$

The column meets the requirements of fire resistance class R 90-A.

In the fire situation, the girder/column connections have to exhibit the same fire resistance as the structural elements.

**Literature**

- Stahlbau Brandschutz Handbuch; Hass, Meyer-Ottens, Richter; Ernst & Sohn, Berlin
- Verbundbau Brandschutz Handbuch; Hass, Meyer-Ottens, Richter, Ernst & Sohn, Berlin
- DIN 4102-4 Fire behaviour of building materials and building components - Part 4, Beuth Verlag, Berlin

**Expert advice**

If you want company-neutral advice, for example at the early draft stage, bauforumstahl is at your service and will gladly offer advice and information.

**Contact:**

Dipl.-Ing. Hans-W. Girkes
Sohnstraße 65
40237 Düsseldorf
Tel.: 0211.6707.826
Fax: 0211.6707.829
brandschutz@bauforumstahl.de
www.bauforumstahl.de/brandschutz