PART 5-6: Beam made of a hollow section

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1 TASK

At this example, a beam made of a welded hollow section has to be dimensioned. It is part of a hall roof structure. The length of the beam is 35.0 m and the beams are arranged at a distance of 10.0 m. It is charged with uniform loads and is restrained against lateral evasion. The beam is executed without any use of fire protection material. The required standard fire resistance class for the tensile bar is R 30.

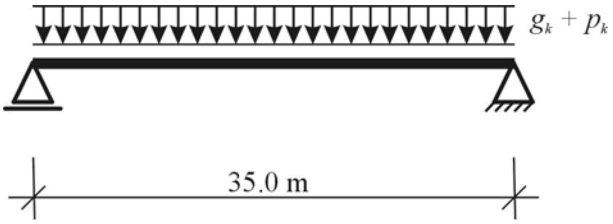

Figure 1. Static system

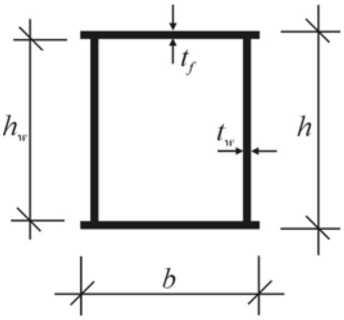

Figure 2. Cross-section

Material properties:
Steel grade: S 355
Yield stress: f_y = 355 N/mm²
Height: h = 700 mm
Height of web: h_w = 650 mm
Width: b = 450 mm
Thickness of flange: t_f = 25 mm

Thickness of web: t_w = 25 mm
Cross-sectional area of the flange: A_f = 11,250 mm²
Cross-sectional area of the web: A_w = 16,250 mm²
Specific heat: c_a = 600 J/(kg·K)
Density: ρ_a = 7850 kg/m³
Emissivity of the beam: ε_m = 0.7
Emissivity of the fire: ε_r = 1.0
Configuration factor Φ = 1.0
Coefficient of the heat transfer: α_c = 25.0 W/m²K
Stephan Boltzmann constant: σ = $5.67 \cdot 10^{-8}$ W/m²K^4
Loads:
Permanent actions:
Beam: $g_{a,k}$ = 4.32 kN/m
Roof: $g_{r,k}$ = 5.0 kN/m
Variable actions:
Snow: $p_{s,k}$ = 11.25 kN/m

2 FIRE RESISTANCE OF BEAM MADE OF A HOLLOW SECTION

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 snow loads is $\psi_{2,1}$ = 0.0. With this parameter, the design bending load is calculated to:

$$M_{fi,d} = \left[\left(4.32 + 5.0\right) + 0.0 \cdot 11.25\right] \cdot \frac{35.0^2}{8} = 1427.1 \text{ kNm}$$

2.2 *Calculation of the steel temperature*

EN 1993-1-2

The temperature increase of the steel section is calculated to:

Section 4.2.5.1

$$\Delta\theta_{a,t} = k_{sh} \cdot \frac{A_m/V}{c_a \cdot \rho_a} \cdot \dot{h}_{net,d} \cdot \Delta t = 1.0 \cdot \frac{40}{600 \cdot 7850} \cdot 5 \cdot \dot{h}_{net} = 4.25 \cdot 10^{-5} \cdot \dot{h}_{net}$$

where:
k_{sh} correction factor for the shadow effect (k_{sh} = 1.0)
Δt time interval (Δt = 5 seconds)
A_m/V section factor for the unprotected beam (Table 4.2)

$$A_m/V = 1/t = 1/0.025 = 40 \ 1/\text{m}$$

The net heat flux is calculated according to EN 1991 Part 1-2.

EN 1991-1-2

$$\dot{h}_{net} = \alpha_c \cdot \left(\theta_g - \theta_m\right) + \Phi \cdot \varepsilon_m \cdot \varepsilon_f \cdot \sigma \cdot \left(\left(\theta_g + 273\right)^4 - \left(\theta_m + 273\right)^4\right)$$

$$= 25 \cdot \left(\theta_g - \theta_m\right) + 3.969 \cdot 10^{-8} \cdot \left(\left(\theta_g + 273\right)^4 - \left(\theta_m + 273\right)^4\right)$$

Section 3.1

The standard temperature-time curve is used for getting the gas temperatures.

$$\theta_g = 20 + 345 \cdot \log_{10}\left(8 \cdot t + 1\right)$$

Section 3.2.1

The steel temperature-time curve of the hollow section is shown in Figure 3:

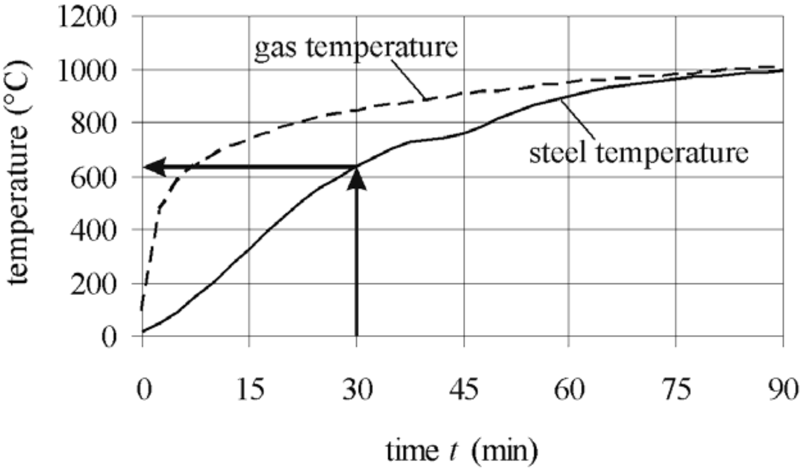

Figure 3. Steel temperature-time curve of the hollow section

$$\Rightarrow \quad \theta_{a,max,30} = 646\ °\mathrm{C}$$

2.3 *Verification in the temperature domain*

EN 1993-1-2

The design moment resistance during fire exposure at the time t = 0 is needed to get the utilization factor.

Section 4.2.3.3

$$M_{fi,Rd,0} = W_{pl} \cdot f_y \cdot k_{y,\theta,\max} / \gamma_{M,fi}$$

$$= 12{,}875{,}000 \cdot 355 \cdot \frac{1.0}{1.0} \cdot 10^{-6}$$

$$= 4570.6\ \mathrm{kNm}$$

where:

$k_{y,\theta,max}$ = 1.0 for θ = 20 °C at the time t = 0

$\gamma_{M,fi}$ = 1.0

and:

$$W_{pl} = 2 \cdot \left(\frac{2 \cdot A_w}{2} \cdot \frac{h_w}{4} + A_f \cdot \frac{h - t_w}{2} \right)$$

$$= 2 \cdot \left(16{,}250 \cdot \frac{650}{4} + 11{,}250 \cdot \frac{700 - 25}{2} \right)$$

$$= 12{,}875{,}000\ \mathrm{mm}^3$$

The utilization factor is calculated to:

Section 4.2.4

$$\mu_0 = E_{fi,d} / R_{fi,d,0} = M_{fi,d} / M_{fi,Rd,0} = 1427.1/4570.6 = 0.31$$

The critical temperature $\theta_{a,cr}$ is given in Table 4.1 of the EN 1993 Part 1-2.

$$\Rightarrow \theta_{a,cr} = 659\ °\mathrm{C}$$

Verification:

$$\frac{646}{659} = 0.98 < 1 \qquad \checkmark$$

2.4 *Verification in the strength domain*

To calculate the moment resistance the reduction factor $k_{y,\theta}$ has to be determined for the temperature $\theta_{a,max,30}$ = 646 °C. This factor is given in Table 3.1 of the EN 1993 Part 1-2:

$$k_{y,\theta} = 0.360$$

Section 3.2.1

Additionally, the adaptation factors κ_1 and κ_2 have to be determined.

The adaptation factor κ_1 considers the non-uniform temperature distribution across the cross-section.

Table 1. Adaptation factor κ_1

Section 4.2.3.3

	κ_1 [-]
Beam exposed on all four sides	1.0
Unprotected beam exposed on three sides with a composite or concrete slab on side four	0.7
Protected beam exposed on three sides with a composite or concrete slab on side four	0.85

The beam in this is an unprotected beam exposed to fire on four sides. Therefore κ_1 is set to:

$$\kappa_1 = 1.0$$

The adaptation factor κ_2 considers the non-uniform temperature distribution along a beam.

Table 2. Adaptation factor κ_2

	κ_2 [-]
At the supports of a statically indeterminate beam	0.85
In all other cases	1.0

The verification is done in the middle of the beam and it is statically determinate. So the adaptation factor κ_2 is set to:

$$\kappa_2 = 1.0$$

Therefore the design moment resistance is calculated to:

$$M_{fi,t,Rd} = M_{pl,Rd,20°C} \cdot k_{y,\theta} \cdot \frac{\gamma_{M,1}}{\gamma_{M,fi}} \cdot \frac{1}{\kappa_1 \cdot \kappa_2}$$

$$= \left(12{,}875{,}000 \cdot 355/1.1\right) \cdot 0.36 \cdot \frac{1.1}{1.0} \cdot \frac{1}{1.0 \cdot 1.0} \cdot 10^{-6} = 1645.4 \text{ kNm}$$

Verification:

$$\frac{1427.1}{1645.4} = 0.87 < 1 \qquad \checkmark$$

REFERENCES

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 1-2: General rules – Structural fire design*, Brussels: CEN, October 2006

QUALITY RECORD	WP5 DIFISEK		
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