PART 5-2: Localized fire

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1 TASK

The steel temperature of a beam has to be determined. It is part of an underground car park below the shopping mall Auchan in Luxembourg. The beams of the car park are accomplished without any use of fire protection material. The most severe fire scenario is a burning car in the middle of the beam (see Figure 1).

For getting the steel temperature, the natural fire model of a localised fire is used.

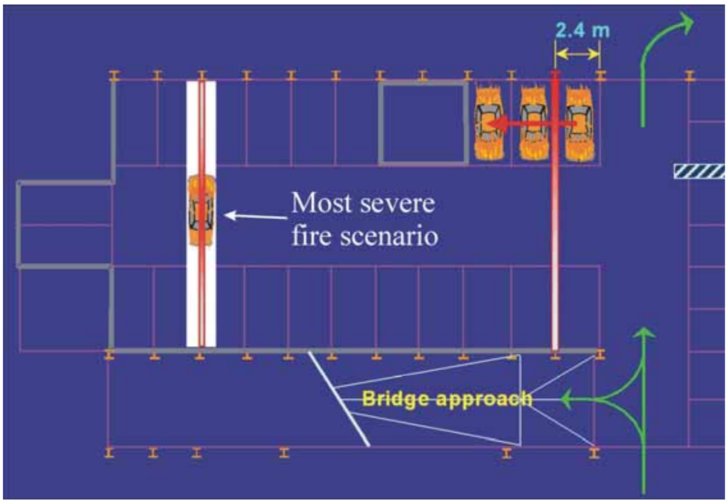

Figure 1. Underground car park of the shopping mall Auchan

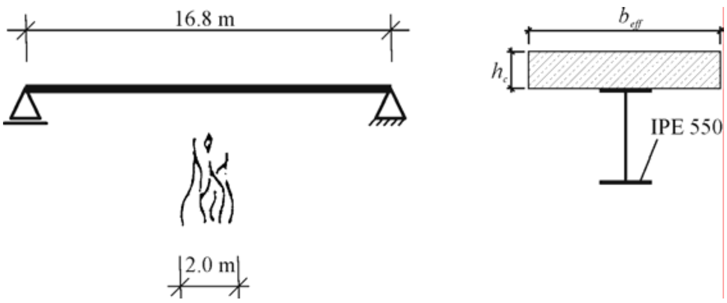

Figure 2. Static system and cross-section of the beam

Diameter of the fire:	D	= 2.0 m
Vertical distance between fire source and ceiling:	H	= 2.7 m
Horizontal distance between beam and flame axis:	r	= 0.0 m
Emissivity of the fire:	ε_f	= 1.0
Configuration factor:	Φ	= 1.0
Stephan Boltzmann constant:	σ	= $5.67 \cdot 10^{-8}$ W/m^{2}K^4
Coefficient of the heat transfer:	α_c	= 25.0 W/m²K

Steel profile:	IPE 550	
Section factor:	A_m/V	= 140 1/m
Unit mass:	ρ_a	= 7850 kg/m³
Surface emissivity:	ε_m	= 0.7
Correction factor:	k_{sh}	= 1.0

2 RATE OF HEAT RELEASE

ECSC Project

The rate of heat release is normally determined by using the EN 1991-1-2 Section E.4. For dimensioning the beams at this car park, the rate of heat release for one car is taken from an ECSC project called "Development of design rules for steel structures subjected to natural fires in CLOSED CAR PARKS" (see Figure 3).

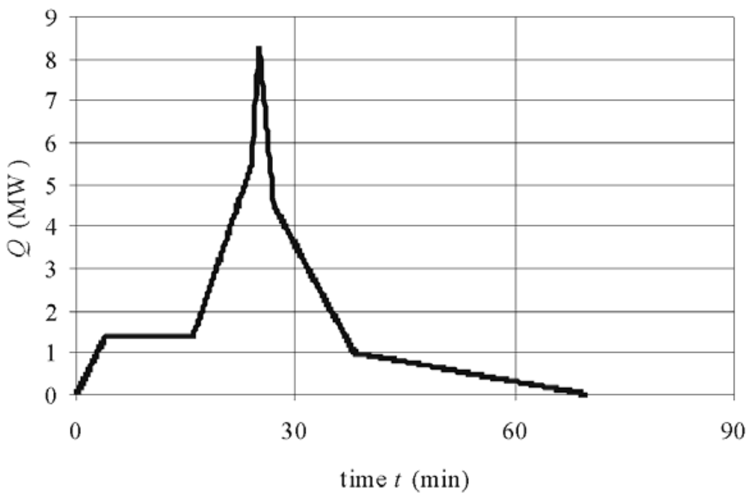

Figure 3. Rate of heat release of one car

3 CALCULATION OF THE STEEL TEMPERATURES

EN 1991-1-2

3.1 *Calculation of the flame length*

Annex C

First of all, the flame length has to be determined.

$$L_f = -1.02 \cdot D + 0.0148 \cdot Q^{2/5} = -2.04 + 0.0148 \cdot Q^{2/5}$$

A plot of this function with the values of Figure 3 is shown in Figure 4. With a ceiling height of 2.80 m, the flame is impacting the ceiling at a time from 16.9 min to 35.3 min (see Figure 4).

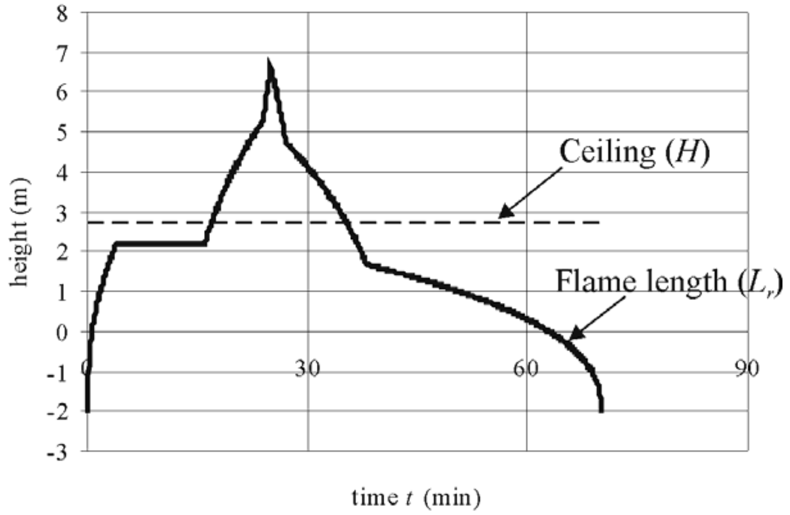

Figure 4. Flame length of the localised fire

It is important to know, if the flame is impacting the ceiling or not, because different calculation methods for the calculation of the net heat flux are used for these two cases (see Figure 5).

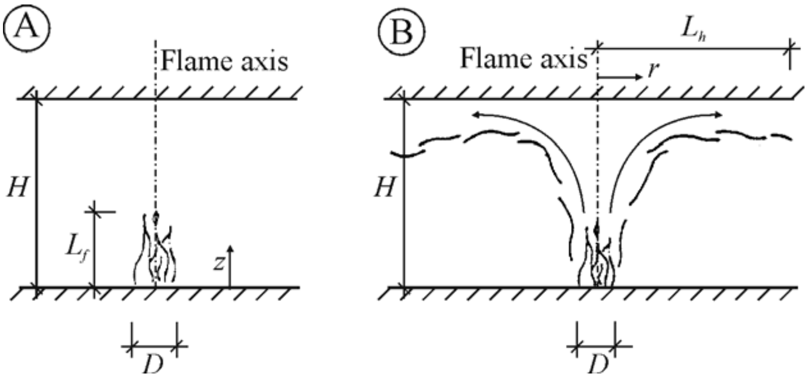

Figure 5. Flame models: Flame is not impacting the ceiling (A); Flame is impacting the ceiling (B)

3.2 *Calculation of the net heat flux*

3.2.1 *1st case: The flame is not impacting the ceiling*

The net heat flux is calculated according to Section 3.1 of EN 1991-1-2.

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

Section 3.1

$$= 25.0 \cdot \left(\theta_{(z)} - \theta_m\right) + 3.969 \cdot 10^{-8} \cdot \left(\left(\theta_{(z)} + 273\right)^4 - \left(\theta_m + 273\right)^4\right)$$

The gas temperature is calculated to:

$$\theta_{(z)} = 20 + 0.25 \cdot (0.8 \cdot Q)^{2/3} \cdot (z - z_0)^{-5/3} \leq 900 \text{ °C}$$
$$= 20 + 0.25 \cdot (0.8 \cdot Q)^{2/3} \cdot \left(4.74 - 0.0052 \cdot Q^{2/5}\right)^{-5/3} \leq 900 \text{ °C}$$

where:

z is the height along the flame axis (2.7 m)
z_0 is the virtual origin of the axis [m]

$$z_0 = -1.02 \cdot D + 0.0052 \cdot Q^{2/5} = -2.04 + 0.0052 \cdot Q^{2/5}$$

3.2.2 *2^nd^ case: The flame is impacting the ceiling*

The net heat flux, if the flame is impacting the ceiling, is given by:

$$\dot{h}_{net} = \dot{h} - \alpha_c \cdot (\theta_m - 20) - \Phi \cdot \varepsilon_m \cdot \varepsilon_f \cdot \sigma \cdot \left((\theta_m + 273)^4 - (293)^4\right)$$
$$= \dot{h} - 25.0 \cdot (\theta_m - 20) - 3.969 \cdot 10^{-8} \cdot \left((\theta_m + 273)^4 - (293)^4\right)$$

The heat flux depends on the parameter y. For different dimensions of y, different equations for determination of the heat flux have to be used.
if $y \leq 0.30$:

$$\dot{h} = 100{,}000$$

if $0.30 < y < 1.0$:

$$\dot{h} = 136{,}300 - 121{,}000 \cdot y$$

if $y \geq 1.0$:

$$\dot{h} = 15{,}000 \cdot y^{-3.7}$$

where:

$$y = \frac{r + H + z'}{L_h + H + z'} = \frac{2.7 + z'}{L_h + 2.7 + z'}$$

The horizontal flame length is calculated to:

$$L_h = \left(2.9 \cdot H \cdot \left(Q_H^*\right)^{0.33}\right) - H = \left(7.83 \cdot \left(Q_H^*\right)^{0.33}\right) - 2.7$$

where:

$$Q_H^* = Q \big/ \left(1.11 \cdot 10^6 \cdot H^{2.5}\right) = Q \big/ \left(1.11 \cdot 10^6 \cdot 2.7^{2.5}\right)$$

The vertical position of the virtual heat source is determined to:
if $Q_D^* < 1.0$:

$$z' = 2.4 \cdot D \cdot \left(\left(Q_D^*\right)^{2/5} - \left(Q_D^*\right)^{2/3}\right) = 4.8 \cdot \left(\left(Q_D^*\right)^{2/5} - \left(Q_D^*\right)^{2/3}\right)$$

if $Q_D^* \geq 1.0$:

$$z' = 2.4 \cdot D \cdot \left(1.0 - \left(Q_D^*\right)^{2/5}\right) = 4.8 \cdot \left(1.0 - \left(Q_D^*\right)^{2/5}\right)$$

where:

$$Q_D^* = Q \big/ \left(1.11 \cdot 10^6 \cdot D^{2.5}\right) = Q \big/ \left(1.11 \cdot 10^6 \cdot 2.0^{2.5}\right)$$

3.3 *Calculation of the steel temperature-time curve*

EN 1993-1-2

The specific heat of the steel c_a is needed to calculate the steel temperature. The parameter is given by EN 1993-1-2, Section 3.4.1.2 depending on the steel temperature.

Section 3.4.1.2

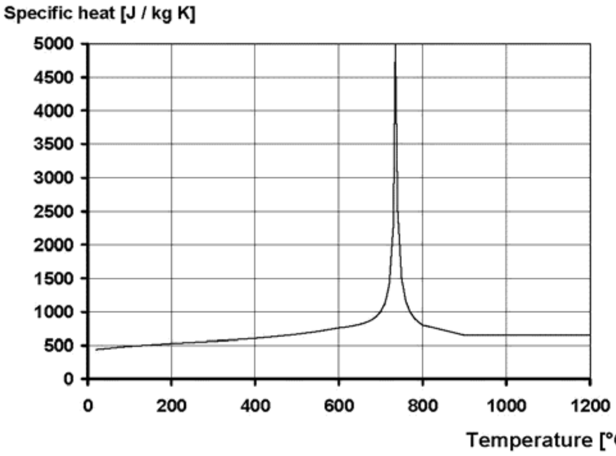

Figure 6. Specific heat of carbon steel (see EN 1993 Part 1-2, Figure 3.4)

$$\theta_{a,t} = \theta_m + k_{sh} \cdot \frac{A_m/V}{c_a \cdot \rho_a} \cdot \dot{h}_{net} \cdot \Delta t = \theta_m + \frac{1.78 \cdot 10^{-2}}{c_a} \cdot \dot{h}_{net}$$

Section 4.2.5.1

The steel temperature-time curve is shown in Figure 6. Additionally, the results of the FEM-analysis done by PROFILARBED are shown for comparison.

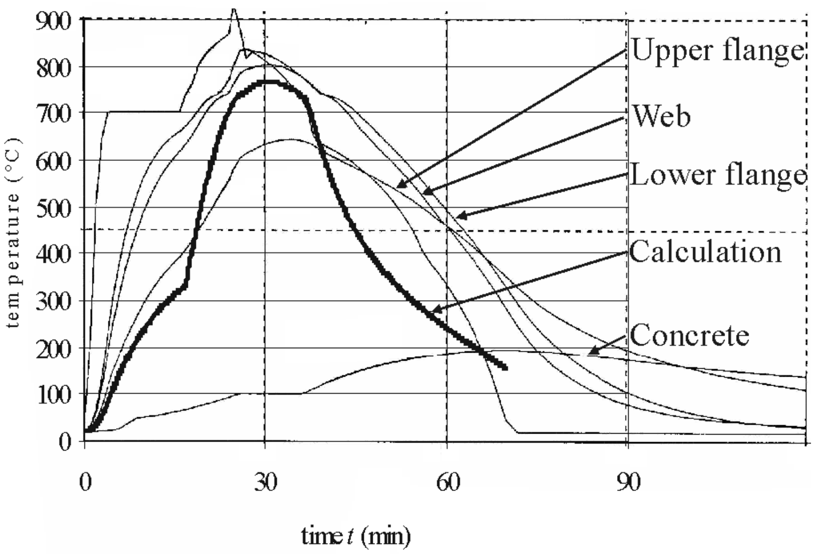

Figure 7. Comparison of the temperature-time curve of the calculation and the FEM-analysis of PROFILARBED

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

ECSC Project, *Development of design rules for steel structures subjected to natural fires in CLOSED CAR PARKS*, CEC agreement 7210-SA/211/318/518/620/933, Brussels, June 1996

QUALITY RECORD	WP5 DIFISEK		
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