



DIFISEK

PART 5a
WORKED EXAMPLES

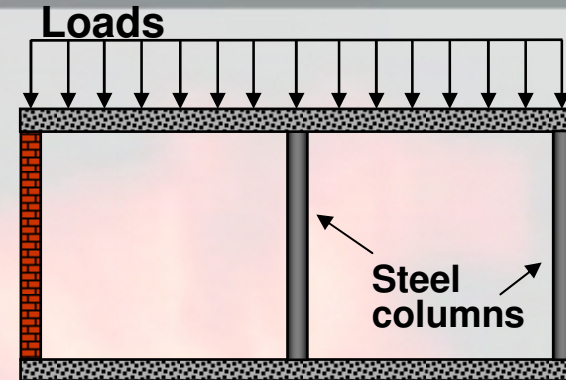
Resistance to fire - Chain of events



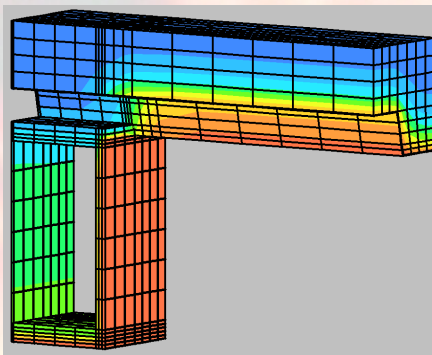
1: Ignition



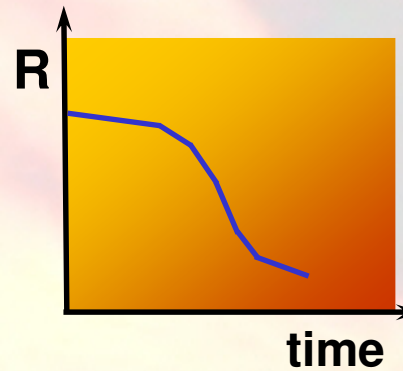
2: Thermal action



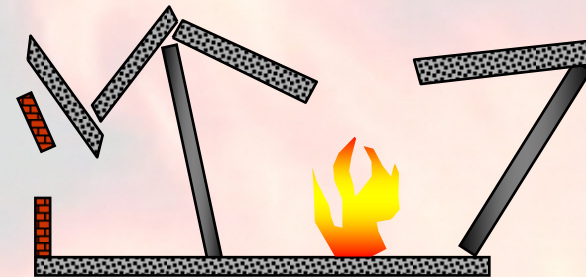
3: Mechanical actions



4: Thermal response



5: Mechanical response



6: Possible collapse

Used standards

Ambient temperature design

- EN 1990 Basis of structural design
- EN 1993-1-1 Design of steel structures
- EN 1994-1-1 Design of composite structures

Fire design

- EN 1990 Basis of structural design
- EN 1991-1-2 Thermal actions
- EN 1993-1-2 Fire design of steel structures
- EN 1994-1-2 Fire design of composite structures

Worked examples – Overview

		Number of examples
➤ EN 1991:	Actions on structures	2
Part 1-2:	General actions – Actions on structures exposed to fire	
➤ EN 1993:	Design of steel structures	3
Part 1-2:	General rules – Structural fire design	
➤ EN 1994:	Design of composite steel and concrete structures	4
Part 1-2:	General rules – Structural fire design	

Worked examples - Overview

➤ Actions

✧ **Compartment fire**

✧ Localised fire

➤ Steel

✧ Steel column

✧ Steel beam (N + M)

✧ Steel beam (hollow section)

➤ Composite

✧ Composite slab

✧ Composite beam (steel beam)

✧ Composite beam (partially encased beam)

✧ Composite column

Compartment Fire

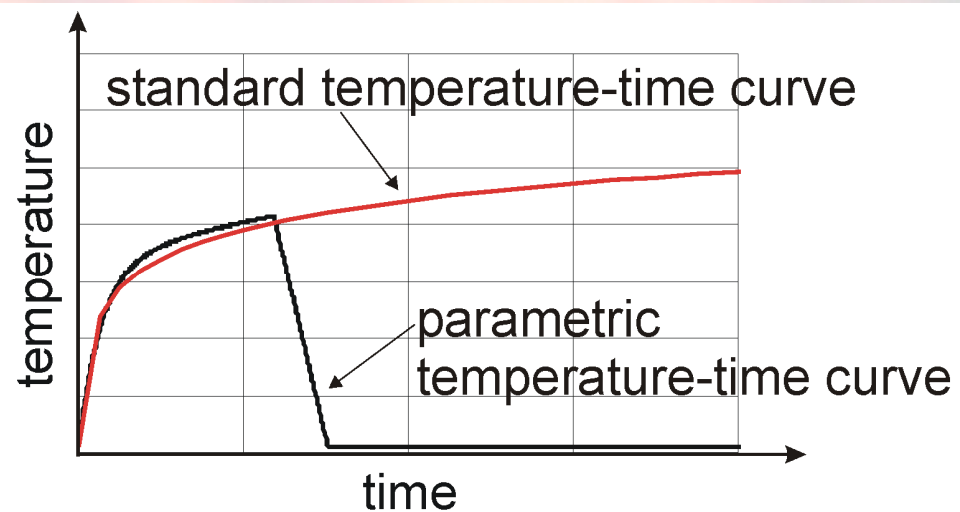
Task

Determination of the gas temperature
of a fully engulfed fire

⇒ Natural fire model for compartment fires

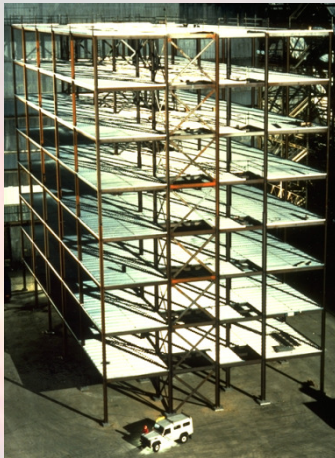
⇒ Parametric temperature – time curve

$$\theta_g = f(q_{f,d}, O, b)$$



EN 1991-1-2: Annex A

Compartment Fire Parameters



Building: Cardington test facility
Type: Office

Fire load: $q_{f,d} = 483 \text{ MJ/m}^2$

Floor area: $A_f = 135 \text{ m}^2$
Height: $H = 4.0 \text{ m}$

Average window height: $h_{eq} = 1.8 \text{ m}$
Area of vertical openings: $A_v = 27 \text{ m}^2$
Vertical opening factor: $O = 0.076 \text{ m}$



Material of boundaries: Lightweight concrete
 $b = 1263.3 \text{ J}/(\text{m}^2\text{s}^{1/2}\text{K})$

Compartment Fire

Fuel or ventilation controlled?

$$0.2 \cdot 10^{-3} \cdot q_{t,d} / O = 0.363 \text{ h}$$

$$0.363 \text{ h} < t_{lim} = 0.333 \text{ h} \quad \text{fuel controlled}$$

$$0.363 \text{ h} > t_{lim} = 0.333 \text{ h} \quad \text{ventilation controlled}$$

where

$$q_{t,d} = q_{f,d} \cdot A_f / A_t$$

Compartment Fire

Heating curve

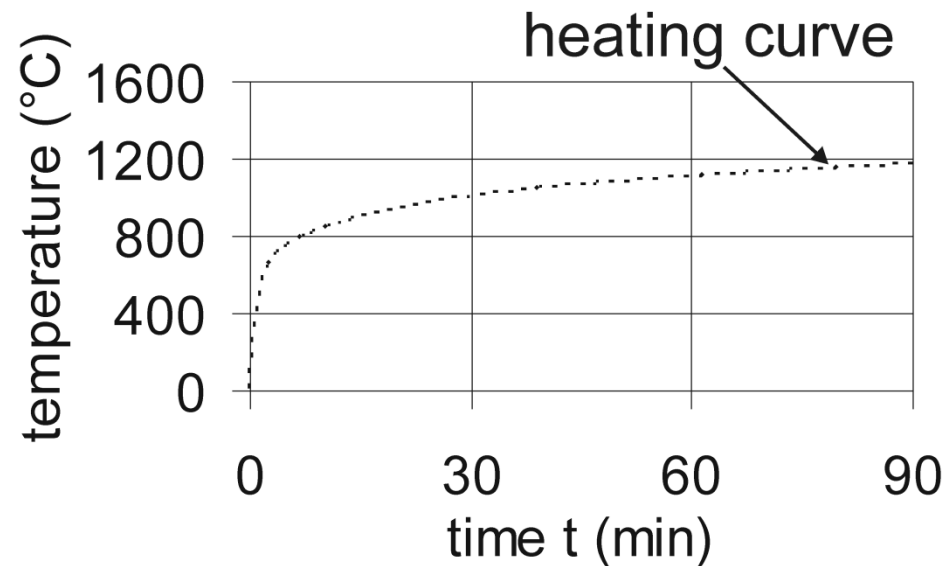
Calculation of the heating curve:

$$\theta_g = 20 + 1325 \cdot (1 - 0.324 \cdot e^{-0.2 \cdot t^*} - 0.204 \cdot e^{-1.7 \cdot t^*} - 0.472 \cdot e^{-19 \cdot t^*})$$

where:

$$t^* = t \cdot \Gamma$$

$$\Gamma = \frac{(O/b)^2}{(0.04/1160)^2}$$



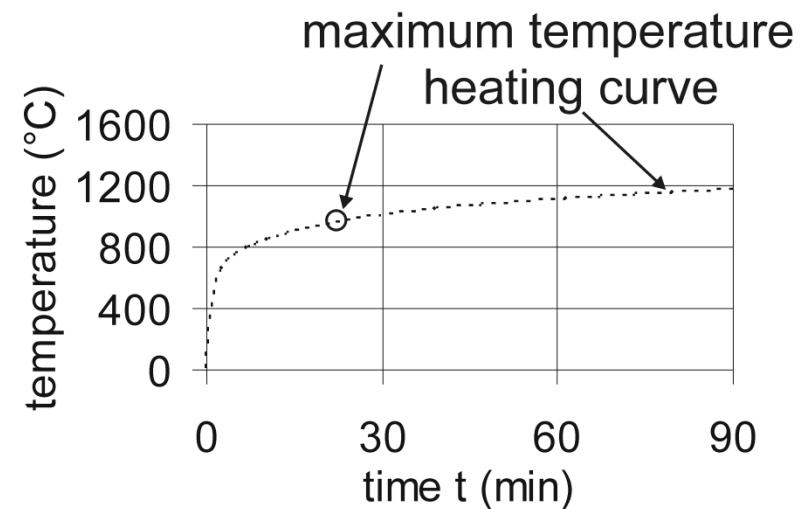
Compartment Fire

Maximum temperature

Equal to the calculation of the heating curve, except:

$$t = t_{\max} = \max \begin{cases} 0.2 \cdot 10^{-3} \cdot q_{t,d} / O \\ t_{\text{lim}} \end{cases}$$

The maximum temperature is needed to determine the cooling curve.



Compartment Fire

Cooling curve

Calculation of the cooling curve:

$$\theta_g = \theta_{\max} - 625 \cdot (t^* - t^*_{\max} \cdot x)$$

where

$$t^*_{\max} = (0.2 \cdot 10^{-3} \cdot q_{t,d} / O) \cdot \Gamma$$

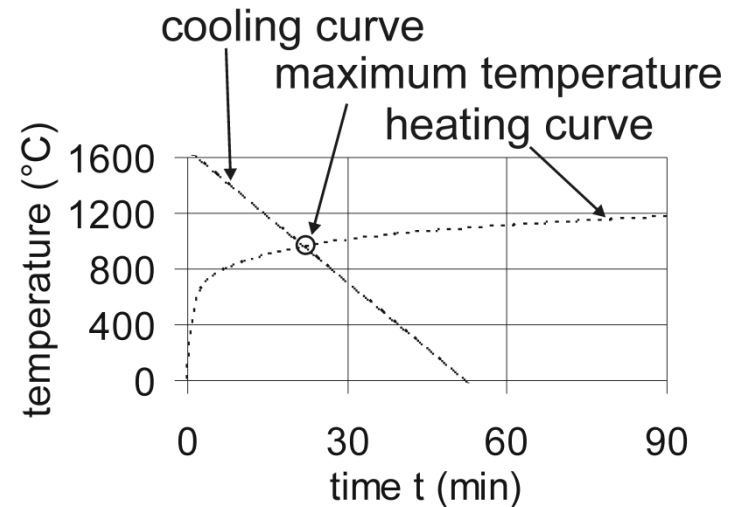
$$t^* = t \cdot \Gamma$$

If fire is ventilation controlled:

$$x = 1.0$$

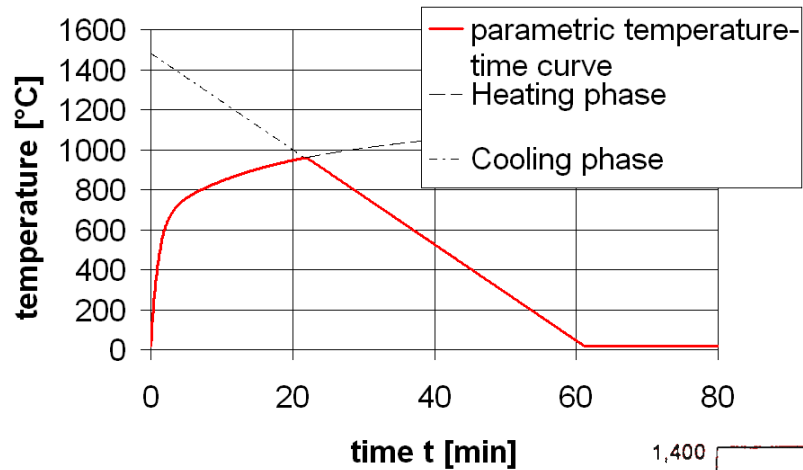
If fire is fuel controlled:

$$x = t_{\text{lim}} \cdot \Gamma / t^*_{\max}$$



Compartment Fire

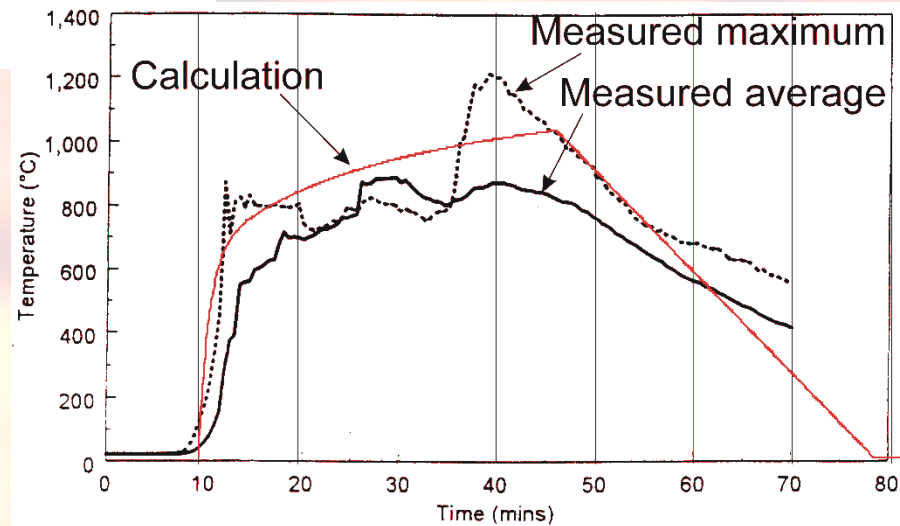
Final curve and comparison



← Parametric temperature-time curve

→ Comparison calculation – measurement

(Factors of $q_{fi,d}$: $\delta_{q1} = 1.0$,
 $\delta_{q2} = 1.0$,
 $\delta_n = 1.0$)



Worked examples - Overview

➤ Actions

- ✧ Compartment fire
- ✧ **Localised fire**

➤ Steel

- ✧ Steel column
- ✧ Steel beam (N + M)
- ✧ Steel beam (hollow section)

➤ Composite

- ✧ Composite slab
- ✧ Composite beam (steel beam)
- ✧ Composite beam (partially encased beam)
- ✧ Composite column

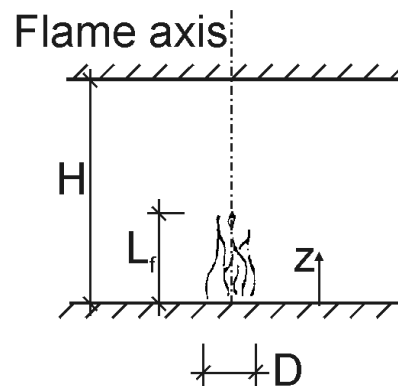
Localised fire

Task

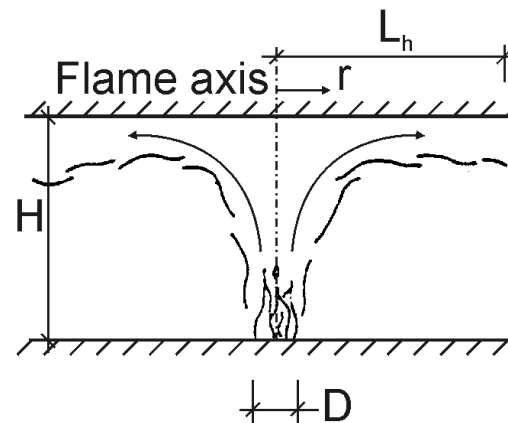
Determination of the steel temperatures of a steel beam exposed to fire by a burning car.

⇒ Natural fire model for localised fires

Not impacting the ceiling

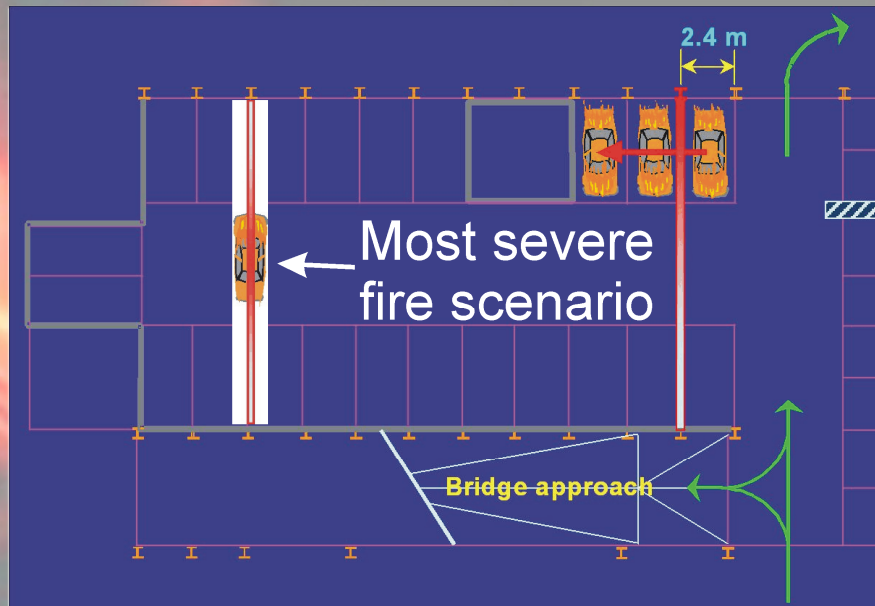


Impacting the ceiling



EN 1991-1-2: Annex C

Localised fire Parameters



Building: Car park Auchan,
Luxembourg
Type: Underground
car park

Height: $H = 2.7$ m

Horizontal distance

from flame axis to beam: $r = 0.0$ m

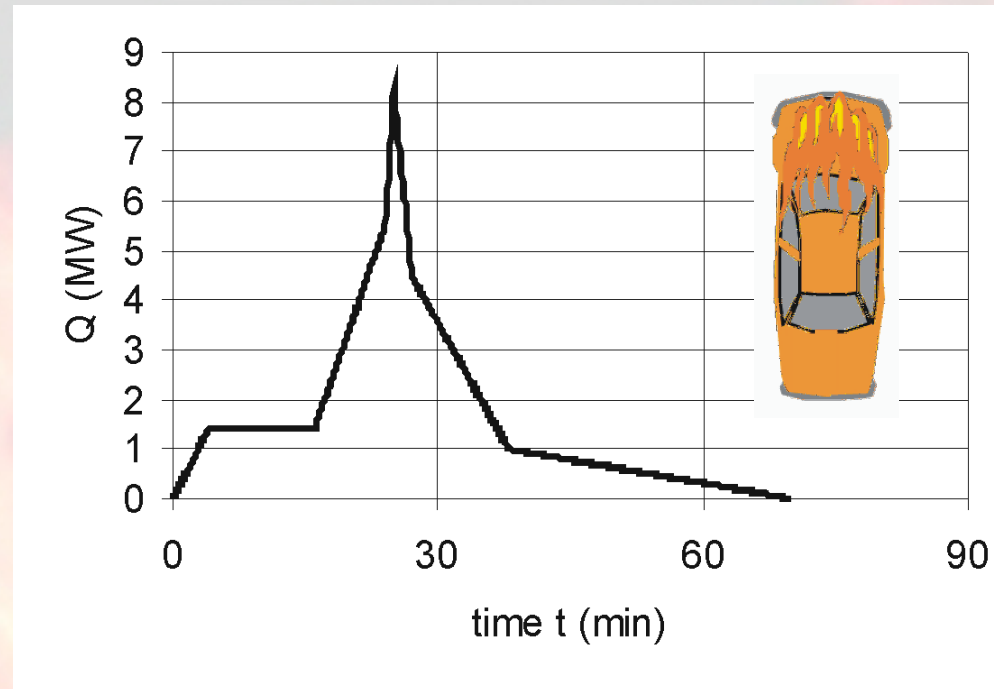
Diameter of flame: $D = 2.0$ m

Steel Beam: IPE 550

Localised fire

Rate of Heat Release

Curve of the rate of heat release of one car



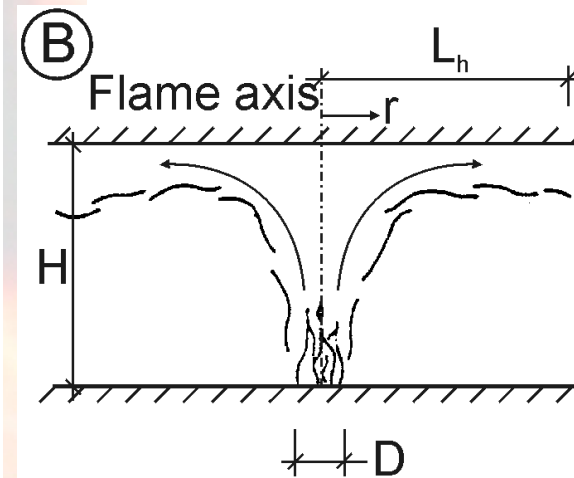
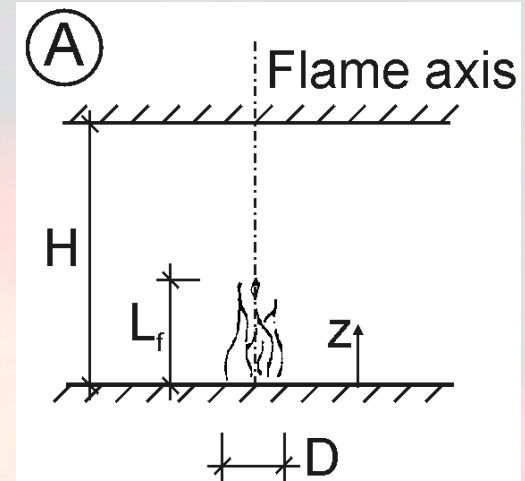
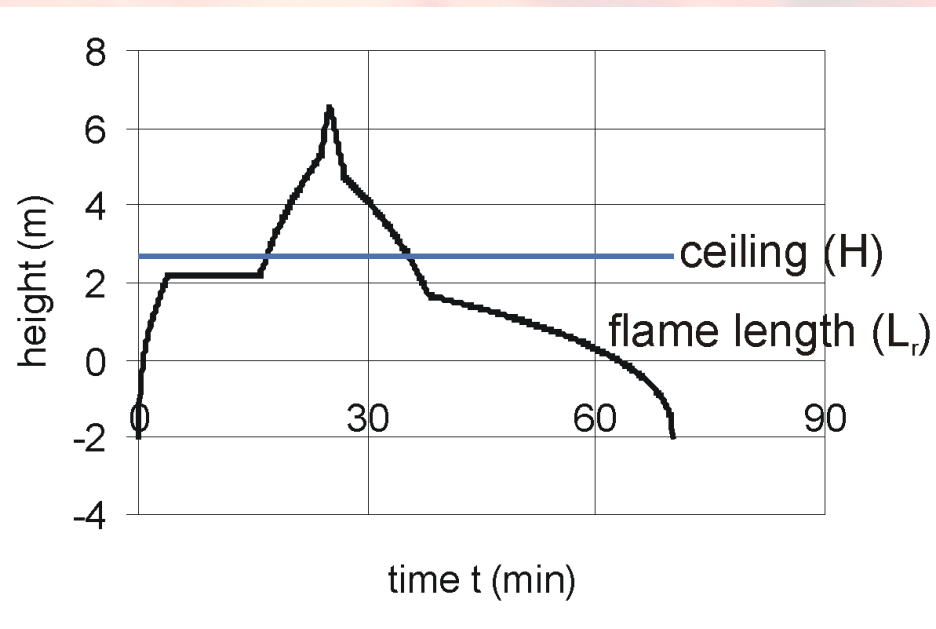
From ECSC project: Development of design rules for steel structures subjected to natural fires in closed car parks.

Localised fire

Flame Length

if $L_r \geq H \Rightarrow$ Model A has to be used

if $L_r < H \Rightarrow$ Model B has to be used



Localised fire

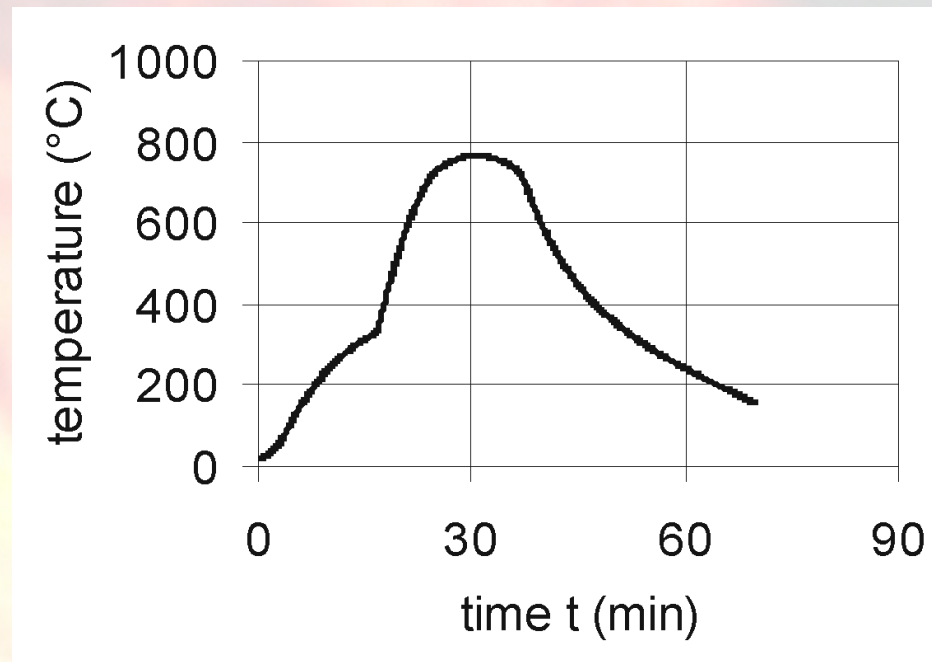
Steel temperatures

Temperature-time curve for the unprotected steel beam:

$$\theta_{a,r} = \theta_m + k_{sh} \cdot \frac{A_p / V}{c_a \cdot \rho_a} \cdot k_{net} \cdot \Delta t$$

$$\theta_{a,max} = 770 \text{ } ^\circ\text{C}$$

at $t_{\theta,max} = 31.07 \text{ min}$



Worked examples - Overview

➤ Actions

- ✧ Compartment fire
- ✧ Localised fire

➤ Steel

- ✧ **Steel column**
- ✧ Steel beam (N + M)
- ✧ Steel beam (hollow section)

➤ Composite

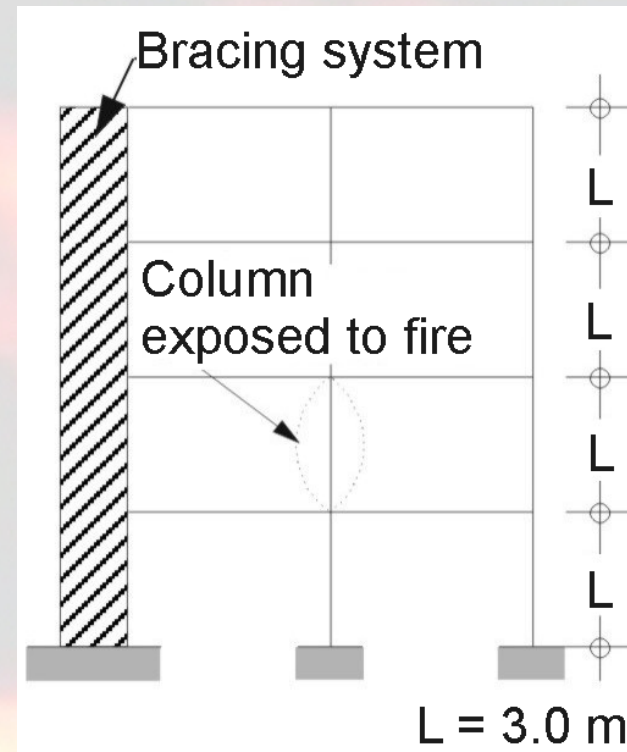
- ✧ Composite slab
- ✧ Composite beam (steel beam)
- ✧ Composite beam (partially encased beam)
- ✧ Composite column

Steel column

Task

Determination of the design axial resistance for a steel column.

⇒ Simple calculation model for compression members



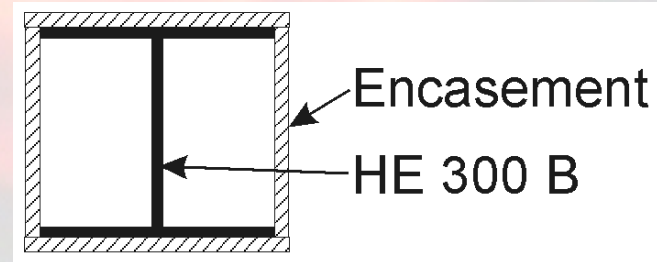
EN 1993-1-2: Section 4.2.3.2

Steel column

Parameters

Building: Department store
Fire resistance class: R 90

Loads: $G_k = 1200$ kN
 $P_k = 600$ kN



Profile: Rolled section
HE 300 B
Fire protection: Hollow encasement
of gypsum board ($d_p = 3$ cm)
Steel grade: S 235

Steel column

Mechanical actions during fire exposure

Accidental situation:

$$E_{dA} = E \cdot (\sum G_k + A_d + \sum \psi_{2,i} \cdot Q_{k,i})$$

Combination factor for shopping areas: $\Rightarrow \psi_{2,1} = 0.6$

$$\Rightarrow N_{fi,d} = 1560 \text{ kN}$$

Steel column

Maximum steel temperature

$$\frac{2 \cdot (b + h)}{A_a} \cdot \frac{\lambda_p}{d_p} = 540 \frac{W}{m^3 \cdot K}$$

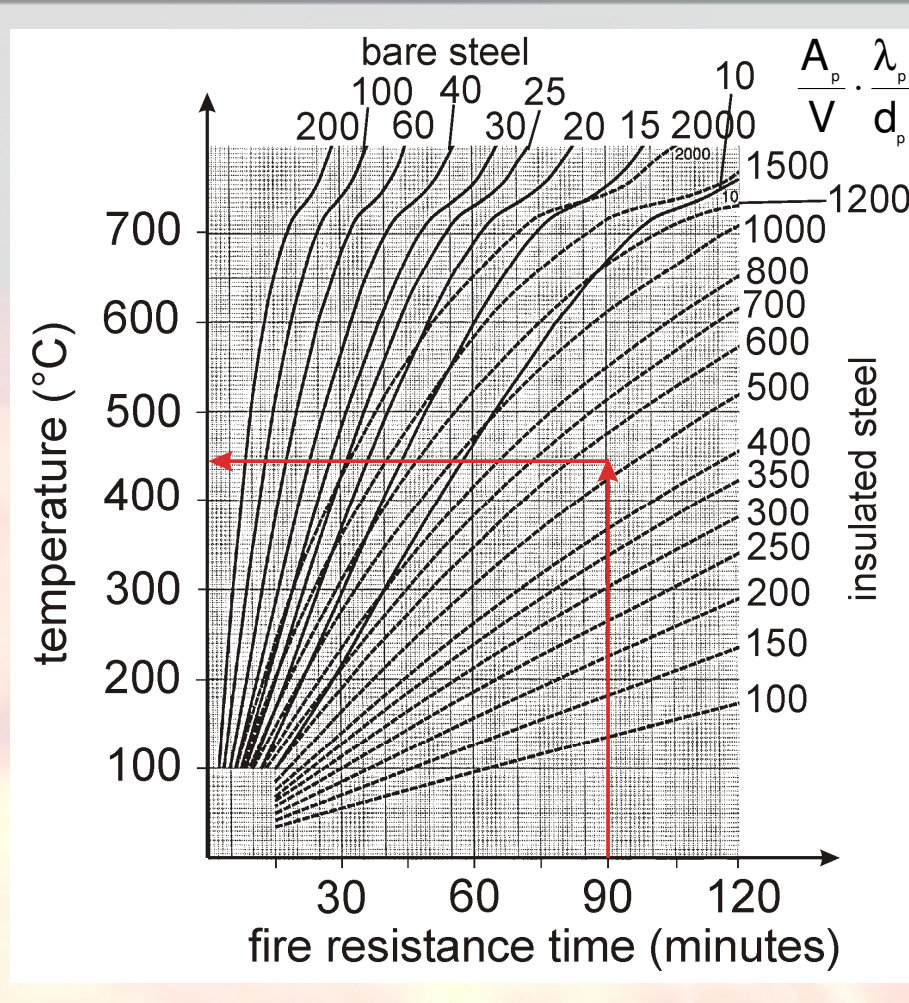
Euro-Nomogram:

$$\Rightarrow \theta_{a,max,90} \approx 445 \text{ } ^\circ\text{C}$$

Reduction factors:

$$\Rightarrow k_{y,\theta} = 0.901$$

$$k_{E,\theta} = 0.655$$



Steel column

Reduction factor and verification

- Reduction factor χ_{fi} :

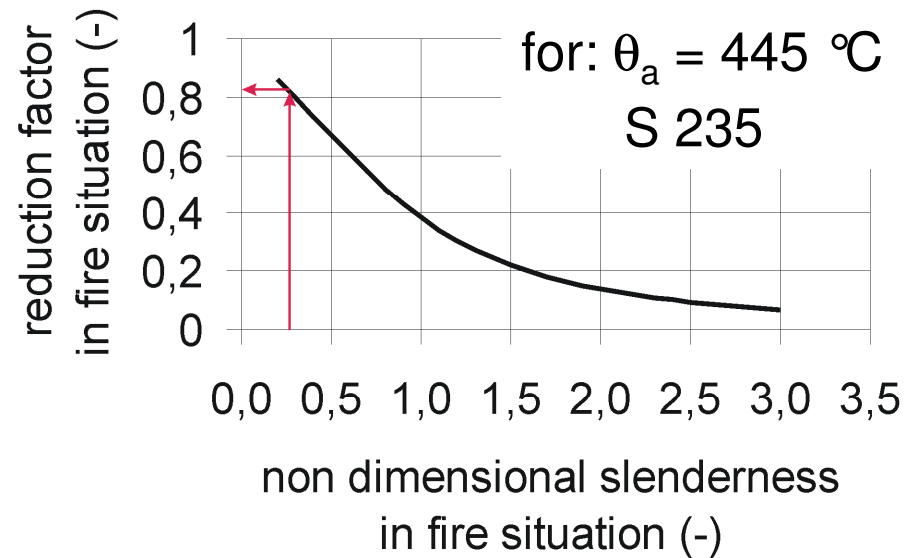
$$\bar{\lambda}_{fi,\theta} = \bar{\lambda} \cdot \sqrt{\frac{k_{y,\theta}}{k_{E,\theta}}} = 0.25$$

$$\Rightarrow \chi_{fi} = 0.86$$

- Flexural buckling:

$$N_{b,fi,t,Rd} = \chi_{fi} \cdot A \cdot k_{y,\theta,max} \cdot \frac{f_y}{\gamma_{M,fi}}$$

$$N_{fi,d}/N_{b,fi,t,Rd} = 0.58 < 1$$



Worked examples - Overview

➤ Actions

- ✧ Compartment fire
- ✧ Localised fire

➤ Steel

- ✧ Steel column
- ✧ **Steel beam (N + M)**
- ✧ Steel beam (hollow section)

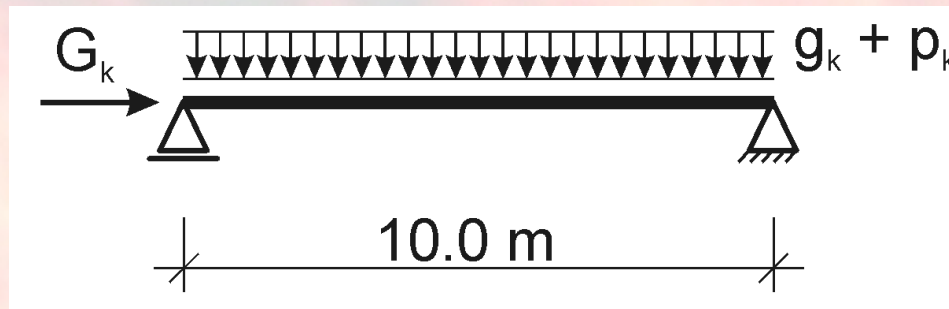
➤ Composite

- ✧ Composite slab
- ✧ Composite beam (steel beam)
- ✧ Composite beam (partially encased beam)
- ✧ Composite column

Steel beam (N + M)

Task

Verification of a steel beam subjected to bending and compression loads.



⇒ Simple calculation model for members subjected to bending and compression loads

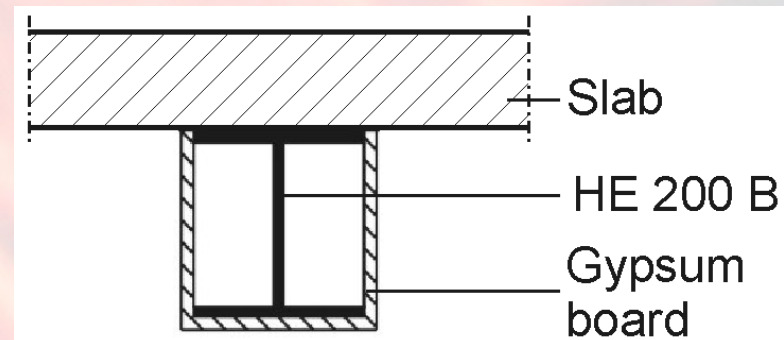
EN 1993-1-2: Section 4.2.3.5

Steel beam (N + M)

Parameters

Building: Office building
Fire resistance
class: R 90

Loads: $G_k = 96.3 \text{ kN}$
 $g_k = 1.5 \text{ kN/m}$
 $p_k = 1.5 \text{ kN/m}$



Profile: Rolled section
HE 200 B

Fire protection: Hollow encasement
of gypsum board ($d_p = 2 \text{ cm}$)

Steel grade: S 235

Steel beam (N + M)

Mechanical actions during fire exposure

Accidental situation:

$$E_{dA} = E \cdot (\sum G_k + A_d + \sum \psi_{2,i} \cdot Q_{k,i})$$

Combination factor for office areas: $\Rightarrow \psi_{2,1} = 0.3$

$$\Rightarrow N_{fi,d} = 96.3 \text{ kN}$$

$$M_{fi,d} = 24.38 \text{ kNm}$$

Steel beam (N + M)

Maximum steel temperature

$$\frac{2 \cdot h + b}{A_a} \cdot \frac{\lambda_p}{d_p} = 770 \frac{W}{m^3 \cdot K}$$

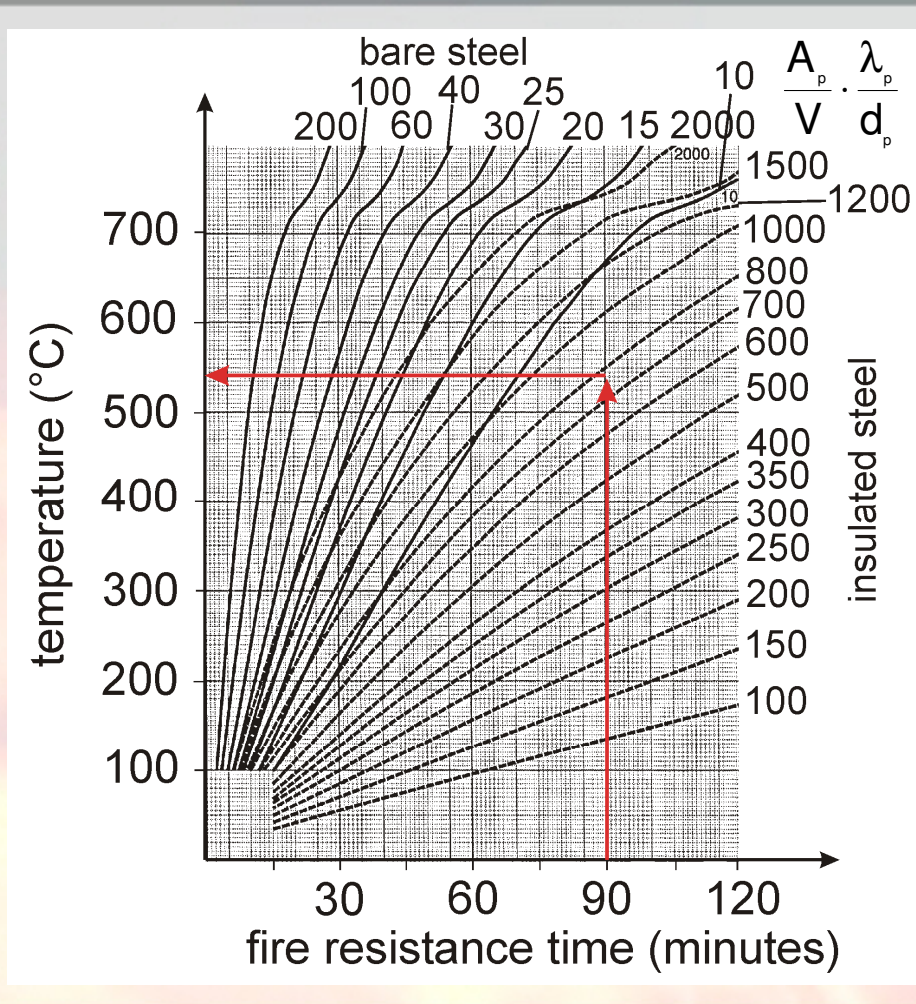
Euro-Nomogram:

$$\Rightarrow \theta_{a,max,90} \approx 540 \text{ } ^\circ\text{C}$$

Reduction factors:

$$\Rightarrow k_{y,\theta} = 0.656$$

$$k_{E,\theta} = 0.484$$



Steel beam (N + M)

Reduction factors and verification

- Reduction factors $\chi_{i,fi}$:

Similar to example „Steel column“

- Flexural buckling:

$$\frac{N_{fi,d}}{\chi_{\min,fi} \cdot A \cdot k_{y,\theta} \cdot f_y / \gamma_{M,fi}} + \frac{k_y \cdot M_{y,fi,d}}{W_{pl,y} \cdot k_{y,\theta} \cdot f_y / \gamma_{M,fi}} = 0.98 \leq 1$$

- Lateral torsional buckling:

$$\frac{N_{fi,d}}{\chi_{z,fi} \cdot A \cdot k_{y,\theta} \cdot f_y / \gamma_{M,fi}} + \frac{k_{LT} \cdot M_{y,fi,d}}{\chi_{LT,fi} \cdot W_{pl,y} \cdot k_{y,\theta} \cdot f_y / \gamma_{M,fi}} = 1.14 \leq 1$$



Worked examples - Overview

➤ Actions

- ✧ Compartment fire
- ✧ Localised fire

➤ Steel

- ✧ Steel column
- ✧ Steel beam (N + M)
- ✧ **Steel beam (hollow section)**

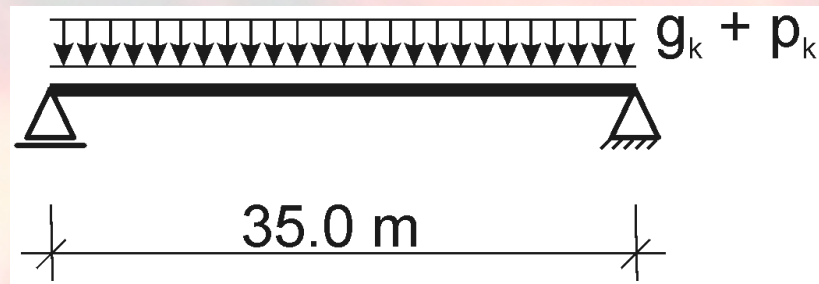
➤ Composite

- ✧ Composite slab
- ✧ Composite beam (steel beam)
- ✧ Composite beam (partially encased beam)
- ✧ Composite column

Steel beam (hollow section)

Task

Determination of the design bending resistance for the steel beam.



⇒ Simple calculation model:

- for members subjected with bending loads
- without stability problems

EN 1993-1-2: Section 4.2.3.3

Steel beam (hollow section)

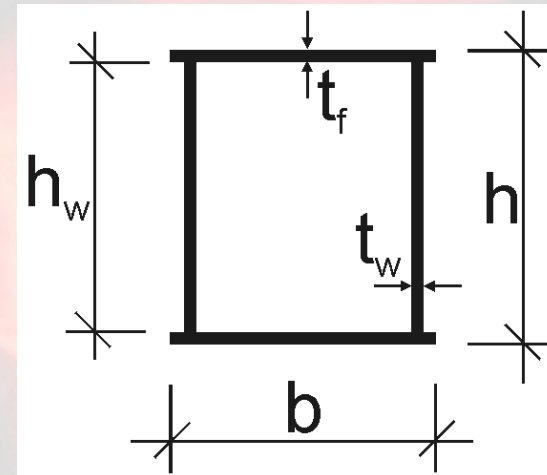
Parameters

Building: Hall roof structure
Fire resistance class: R 30

Loads: $g_k = 9.32 \text{ kN/m}$
 $p_k = 11.25 \text{ kN/m}$

Profile: Welded section
 $h / b = 70 \text{ cm} / 45 \text{ cm}$
 $t_w = t_f = 25 \text{ mm}$

Fire protection: none
Steel grade: S 355



Steel beam (hollow section)

Mechanical actions during fire exposure

Accidental situation:

$$E_{dA} = E \cdot (\sum G_k + A_d + \sum \psi_{2,i} \cdot Q_{k,i})$$

Combination factor for snow loads: $\Rightarrow \psi_{2,1} = 0.0$

$$\Rightarrow M_{fi,d} = 1427.1 \text{ kNm}$$

Steel beam (hollow section)

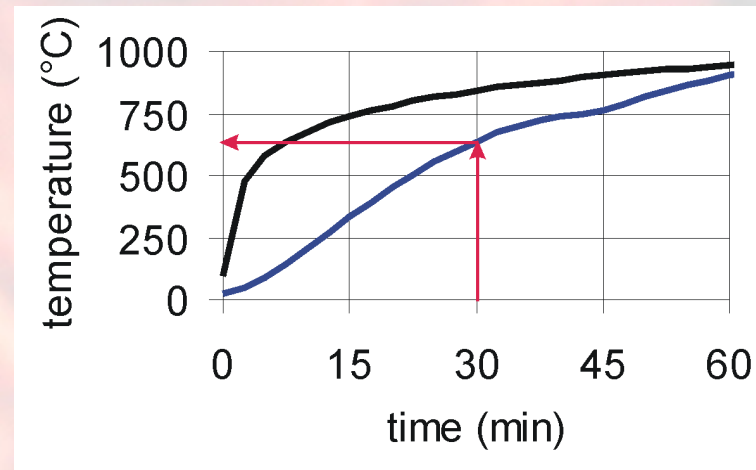
Maximum steel temperature

- Standard temperature – time curve:

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

- Steel temperature – time curve:

$$\Delta\theta_{a,r} = k_{sh} \cdot \frac{A_p / V}{c_a \cdot \rho_a} \cdot k_{net} \cdot \Delta t$$



Section factor with equal thickness of flanges and web.

$$\Rightarrow \frac{A_p}{V} = \frac{1}{t} = 40 \frac{1}{m}$$

Steel beam (hollow section)

Verification

- Verification in the temperature domain:

$$\mu_0 = E_{fi,d}/R_{fi,d,0} = 0.31$$

$$\Rightarrow \theta_{a,cr} = 659 \text{ }^\circ\text{C}$$

$$\frac{\theta_{a,max,30}}{\theta_{a,cr}} = 0.98 < 1$$

- Verification in the strength domain:

$$M_{fi,t,Rd} = M_{pl,Rd,20^\circ\text{C}} \cdot k_{y,\theta} \cdot \frac{\gamma_{M,1}}{\gamma_{M,fi}} \cdot \frac{1}{\kappa_1 \cdot \kappa_2} = 1645.4 \text{ kNm}$$

where

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

$$\kappa_1 = 1.0$$

$$\kappa_2 = 1.0$$

$$\frac{M_{fi,d}}{M_{fi,t,Rd}} = 0.87 < 1$$

Worked examples - Overview

➤ Actions

- ✧ Compartment fire
- ✧ Localised fire

➤ Steel

- ✧ Steel column
- ✧ Steel beam (N + M)
- ✧ Steel beam (hollow section)

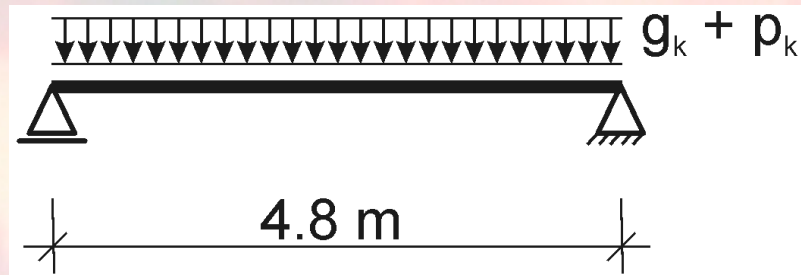
➤ Composite

- ✧ **Composite slab**
- ✧ Composite beam (steel beam)
- ✧ Composite beam (partially encased beam)
- ✧ Composite column

Composite slab

Task

Determination of the design sagging moment resistance for the composite slab.



⇒ Simple calculation model for composite slabs exposed to fire

EN 1994-1-2: Annex D

Composite slab

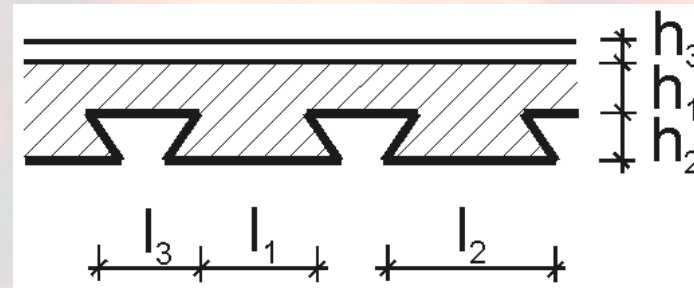
Parameters

Building: Shopping centre
Fire resistance
class: R 90

Loads: $g_k = 4.62 \text{ kN/m}^2$
 $p_k = 5.0 \text{ kN/m}^2$

Height of slab: $h = 14.0 \text{ cm}$
Strength class: C 25/30

Steel sheet: Re-entrant
 $h_2 = 5.1 \text{ cm}$
Yield stress: $f_y = 350 \text{ N/mm}^2$



Composite slab

Mechanical actions during fire exposure

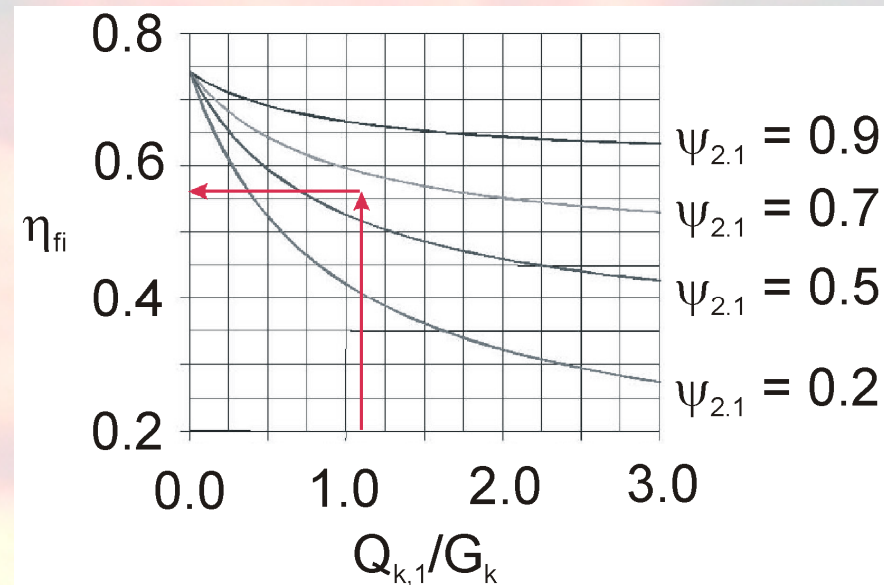
Accidental situation:

$$E_{dA} = E \cdot (\sum G_k + A_d + \sum \psi_{2,i} \cdot Q_{k,i})$$

$$\frac{Q_{k,1}}{G_k} = \frac{q_{k,1}}{g_k} = 1.1$$

Bending moment
in fire situation:

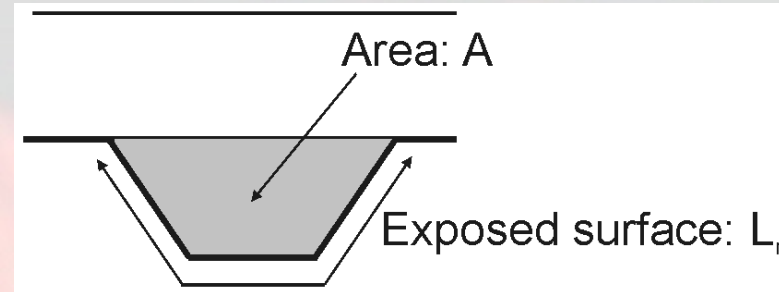
$$M_{fi,d} = \eta_{fi} \cdot M_{sd} = 21.76 \text{ kNm/m}$$



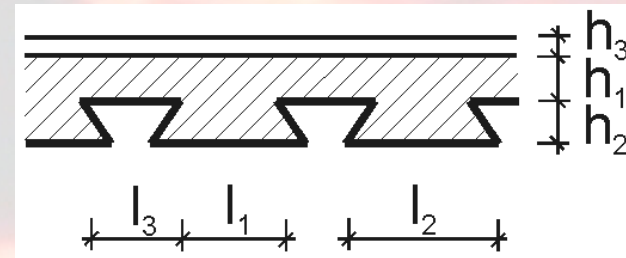
Composite slab

Rib geometry factor

Rib geometry factor considers positive effects of mass and height of the rib.



$$\frac{A}{L_r} = \frac{h_2 \cdot \left(\frac{l_1 + l_2}{2}\right)}{l_2 + 2 \cdot \sqrt{h_2^2 + \left(\frac{l_1 - l_2}{2}\right)^2}} = 27 \text{ mm}$$

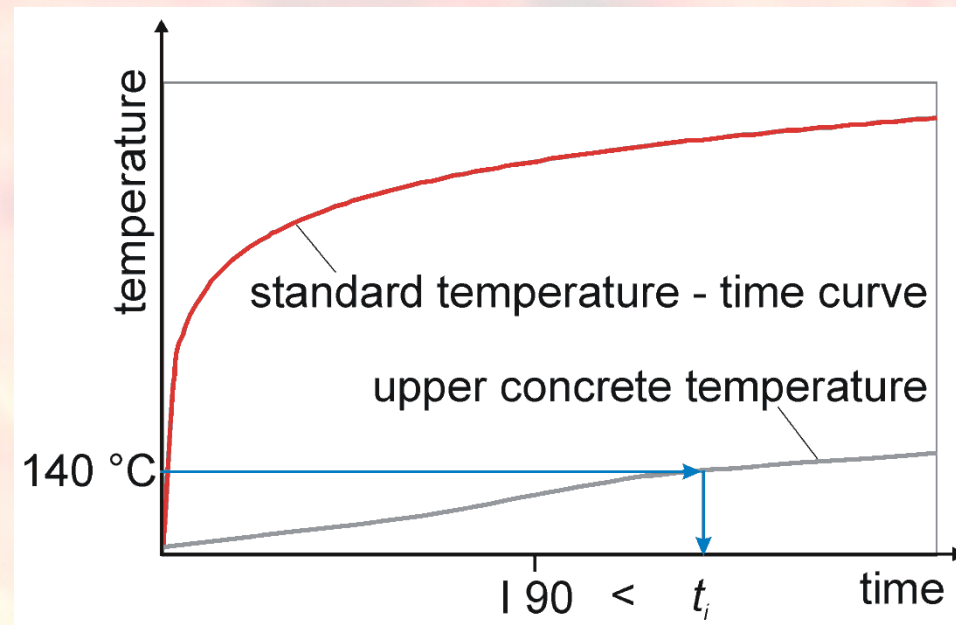


Composite slab

Thermal insulation

The temperature on top of the slab should not exceed 140 °C in average and 180 °C at its maximum.

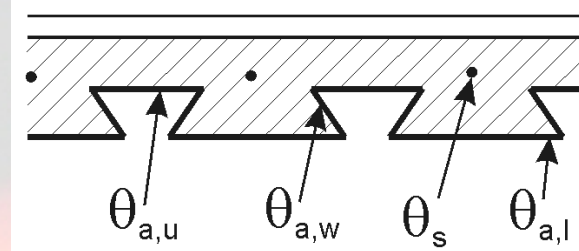
$$t_i = 131.48 \text{ min} > 90 \text{ min}$$



Composite slab

Maximum steel temperatures and verification

- Calculation of the steel temperatures:



Steel sheet

$$\theta_{a,i} = b_{0,i} + b_{1,i} \cdot \frac{1}{l_3} + b_{2,i} \cdot \frac{A}{L_r} + b_{3,i} \cdot \Phi + b_{4,i} \cdot \Phi^2$$

Reinforcement bars

$$\theta_s = c_0 + c_1 \cdot \frac{u_3}{h_2} + c_2 \cdot z + c_3 \cdot \frac{A}{L_r} + c_4 \cdot \alpha + c_5 \cdot \frac{1}{l_3}$$

- Verification:

$$M_{fi,t,Rd} = \sum A_i \cdot z_i \cdot k_{y,\theta,i} \cdot \left(\frac{f_{y,i}}{\gamma_{M,fi}} \right) + \alpha_{slab} \cdot \sum A_j \cdot z_j \cdot k_{c,\theta,j} \cdot \left(\frac{f_{c,j}}{\gamma_{M,fi,c}} \right)$$

$$= 25.00 \text{ kNm/m} > 21.76 \text{ kNm/m}$$

Worked examples - Overview

➤ Actions

- ✧ Compartment fire
- ✧ Localised fire

➤ Steel

- ✧ Steel column
- ✧ Steel beam (N + M)
- ✧ Steel beam (hollow section)

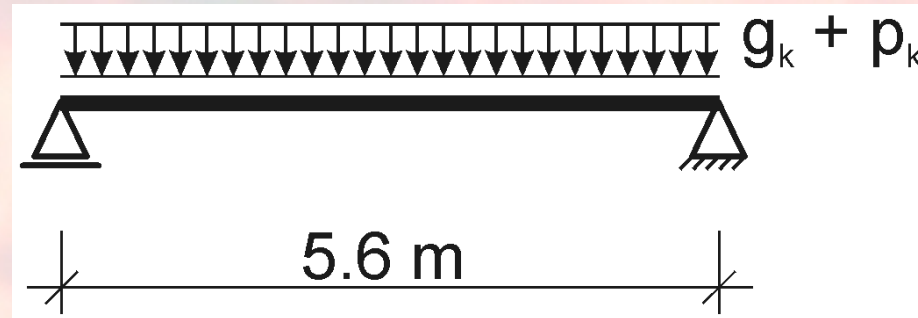
➤ Composite

- ✧ Composite slab
- ✧ **Composite beam (steel beam)**
- ✧ Composite beam (partially encased beam)
- ✧ Composite column

Composite beam (steel beam)

Task

Determination of the design sagging moment resistance for the composite beam.



⇒ Simple calculation model for composite beams exposed to fire

EN 1994-1-2: Annex E

Composite beam (steel beam)

Parameters

Building: Office building

Fire resistance class: R 60

Loads: $g_k = 28.0$ kN/m

$p_k = 15.0$ kN/m

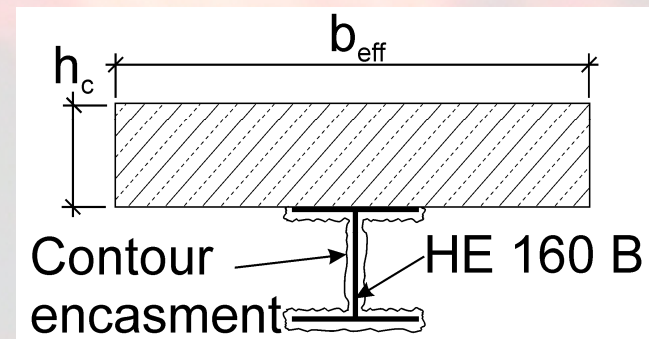
Height of slab: $h_c = 16.0$ cm

Strength class: C 25/30

Profile: Rolled section
HE 160 B

Fire protection: Contour
encasement
of plaster ($d_p = 1.5$ cm)

Steel grade: S 235



Composite beam (steel beam)

Mechanical actions during fire exposure

Accidental situation:

$$E_{dA} = E \cdot (\sum G_k + A_d + \sum \psi_{2,i} \cdot Q_{k,i})$$

Combination factor for office areas: $\Rightarrow \psi_{2,1} = 0.3$

$$\Rightarrow M_{fi,d} = 127.4 \text{ kNm}$$

Composite beam (steel beam)

Maximum steel temperature

Upper flange:

$$\theta_{a,max,u} \approx 390 \text{ }^{\circ}\text{C}$$

$$\Rightarrow k_{y,\theta} = 1.0$$

Web:

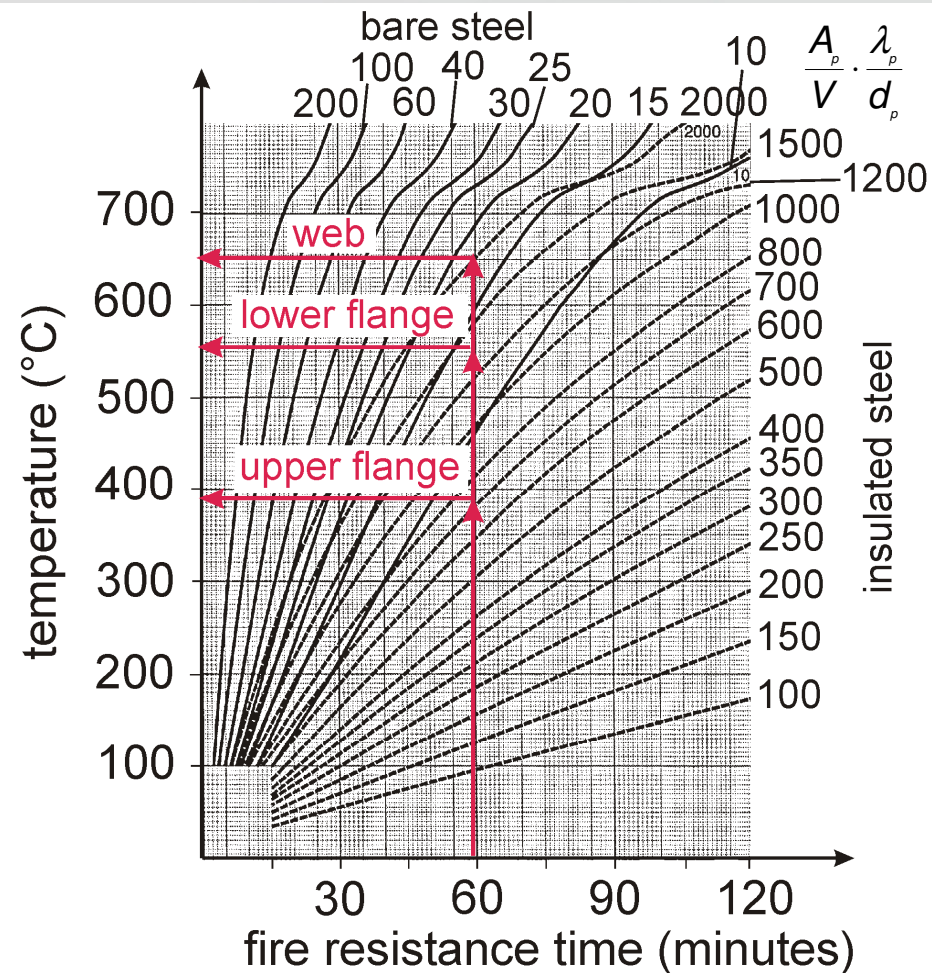
$$\theta_{a,max,w} \approx 650 \text{ }^{\circ}\text{C}$$

$$\Rightarrow k_{y,\theta} = 0.350$$

Lower flange:

$$\theta_{a,max,l} \approx 550 \text{ }^{\circ}\text{C}$$

$$\Rightarrow k_{y,\theta} = 0.625$$



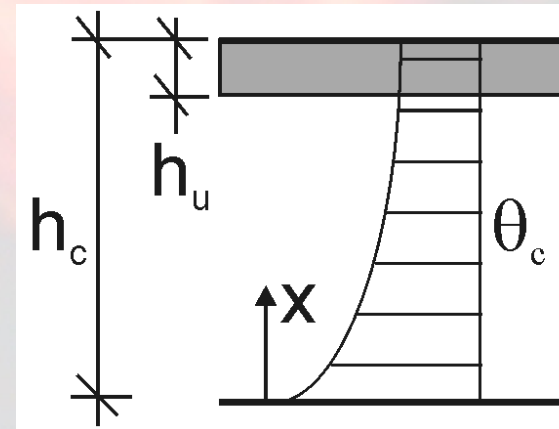
Composite beam (steel beam)

Temperatures of the concrete compression zone

Check, if the temperatures in the compression zone are lower than 250 °C:

$$(h_c - h_u) = 12.2 \text{ cm} > x = 5 \text{ cm}$$

⇒ Concrete compression strength is not reduced.



where

x : Concrete zone with temperatures $\theta_c > 250 \text{ °C}$

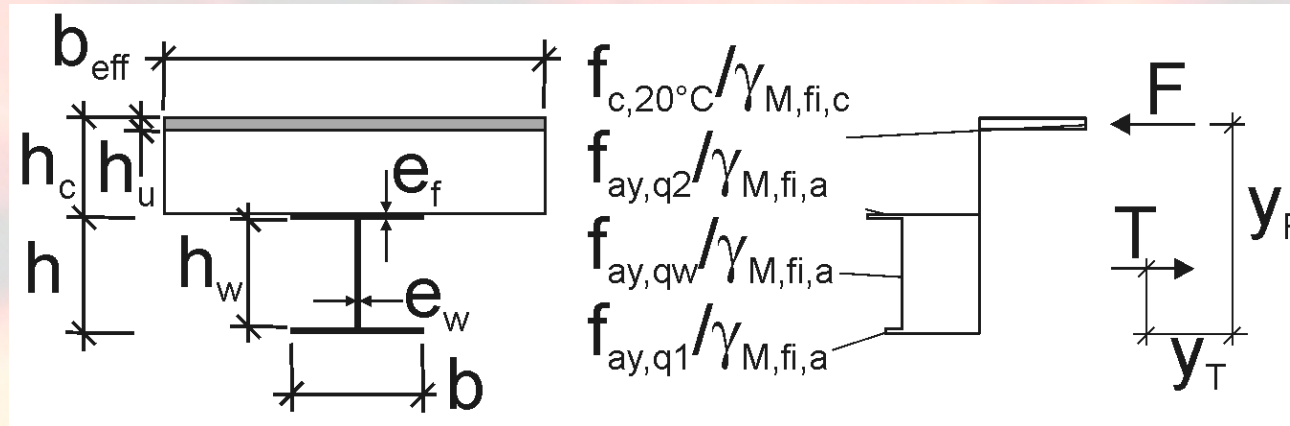
h_u : Height of the compression zone

Composite beam (steel beam)

Design sagging moment resistance and verification

- Design sagging moment resistance:

$$M_{fi,Rd} = T \cdot (y_F - y_T) = 274.2 \text{ kNm}$$



- Verification:

$$\frac{M_{fi,d}}{M_{fi,Rd}} = 0.46 < 1$$

Worked examples - Overview

- Actions
 - ✧ Compartment fire
 - ✧ Localised fire

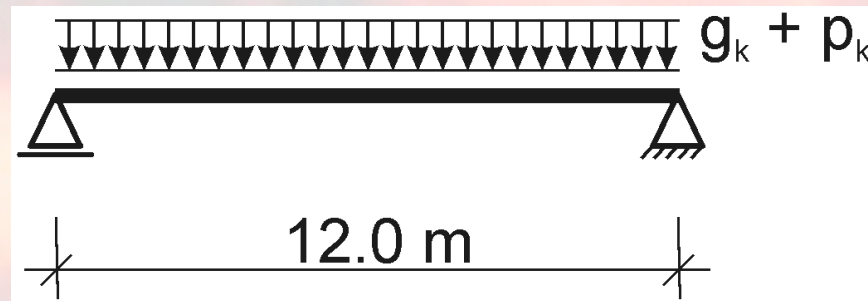
- Steel
 - ✧ Steel column
 - ✧ Steel beam (N + M)
 - ✧ Steel beam (hollow section)

- Composite
 - ✧ Composite slab
 - ✧ Composite beam (steel beam)
 - ✧ **Composite beam (partially encased beam)**
 - ✧ Composite column

Composite beam (partially encased beam)

Task

Determination of the design sagging moment resistance for the composite beam



⇒ Simple calculation model for composite beams comprising steel beam with partial concrete encasement exposed to fire.

EN 1994-1-2: Annex F

Composite beam (partially encased beam)

Parameters

Building: Storehouse

Fire resistance class: R 90

Loads: $g_k = 21.0$ kN/m
 $p_k = 30.0$ kN/m

Height of slab: $h_c = 16$ cm

Strength category: C 25/30

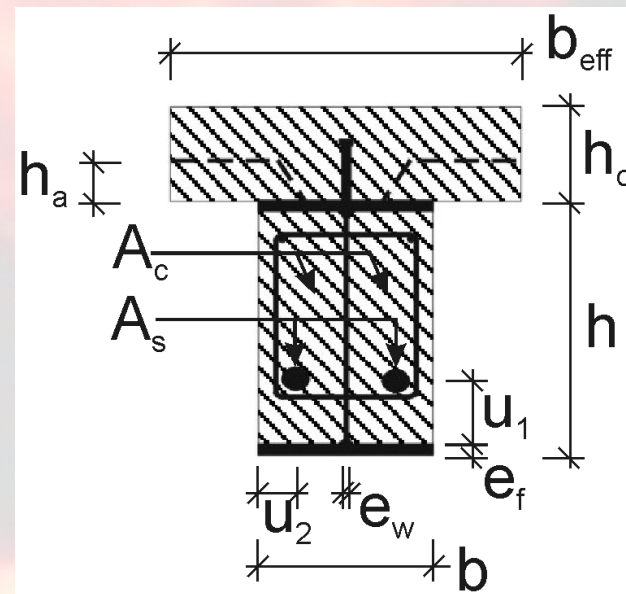
Width of encasement: $b_c = b = 20$ cm

Strength class: C 25/30

Profile: Rolled section

IPE 500

Steel grade: S 355



Composite beam (partially encased beam)

Mechanical actions during fire exposure

Accidental situation:

$$E_{dA} = E \cdot (\sum G_k + A_d + \sum \psi_{2,i} \cdot Q_{k,i})$$

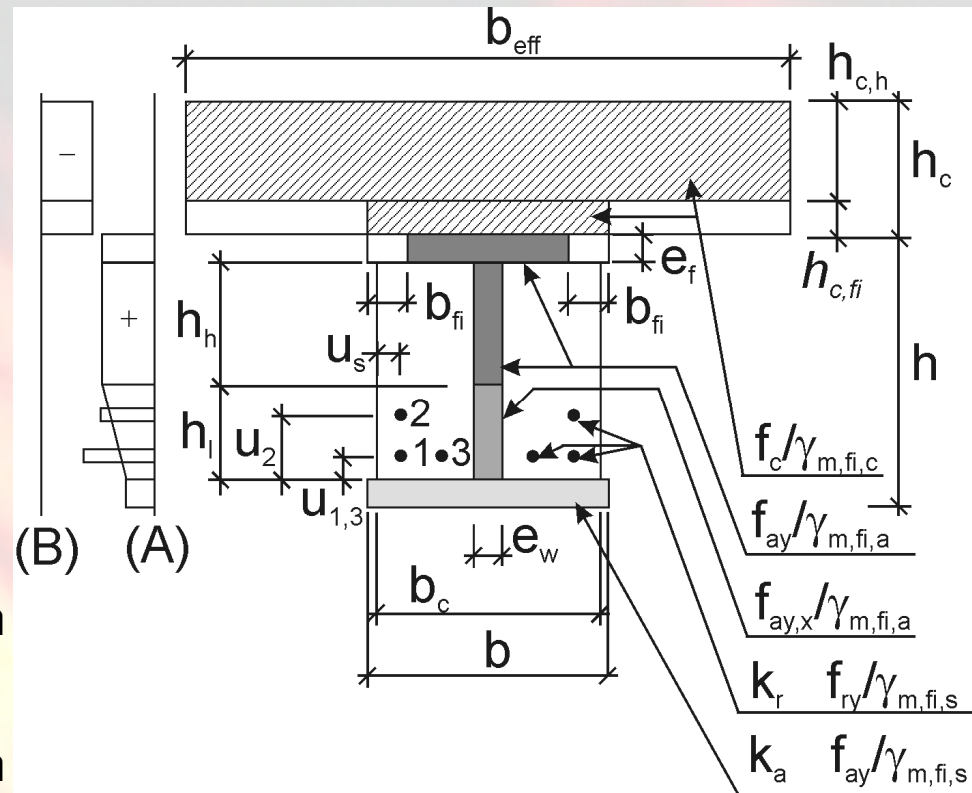
Combination factor for storage areas: $\Rightarrow \psi_{2,1} = 0.8$

$$\Rightarrow M_{fi,d} = 810.0 \text{ kNm}$$

Composite beam (partially encased beam)

Reduction of the cross-section in the fire situation

- Concrete slab
 - ⊠ Height reduction
- Upper flange
 - ⊠ Width reduction
- Web
 - ⊠ Determination of height without strength reduction
- Lower flange
 - ⊠ Strength reduction
- Reinforcements
 - ⊠ Strength reduction



Composite beam (partially encased beam)

Design sagging moment resistance and verification

- Design sagging moment resistance:

$$M_{fi,Rd} = \sum T_i \cdot z_i = 942.7 \text{ kNm}$$

where

T_i : tension force of part of the cross-section

z_i : distance from compression force to the tension force

- Verification:

$$\frac{M_{fi,d}}{M_{fi,Rd}} = 0.86 < 1$$

Worked examples - Overview

➤ Actions

- ✧ Compartment fire
- ✧ Localised fire

➤ Steel

- ✧ Steel column
- ✧ Steel beam (N + M)
- ✧ Steel beam (hollow section)

➤ Composite

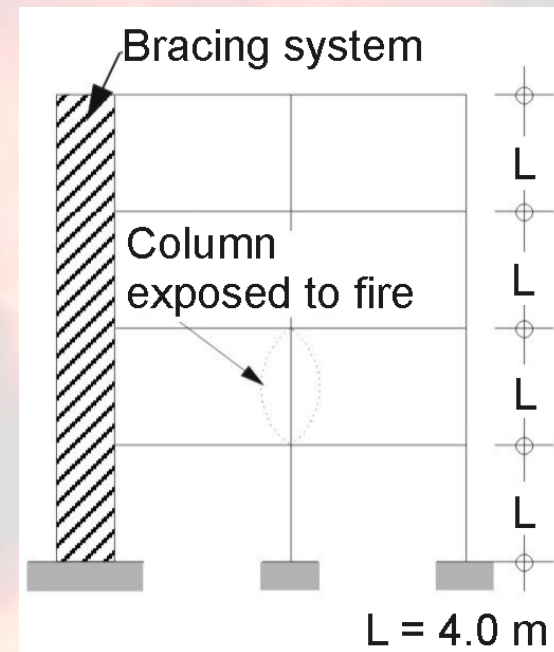
- ✧ Composite slab
- ✧ Composite beam (steel beam)
- ✧ Composite beam (partially encased beam)
- ✧ **Composite column**

Composite column

Task

Determination of the design axial compression resistance for the composite column.

⇒ Simple calculation model
for composite columns exposed
to fire and tabulated data method



EN 1994-1-2: Annex G

EN 1994-1-2: Section 4.2.3.3

Composite column

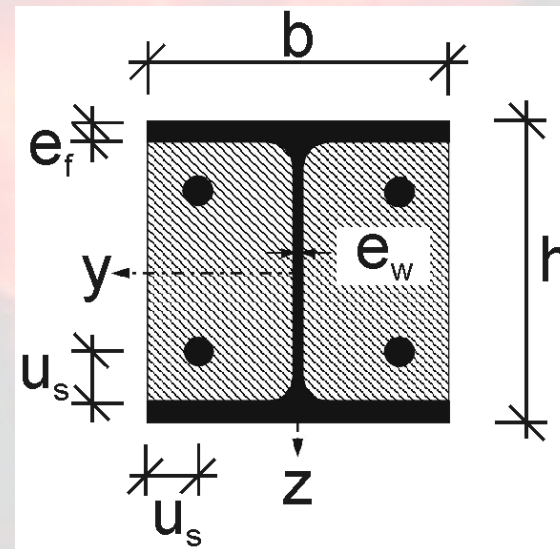
Parameters

Building: Office building
Fire resistance class: R 60

Loads: $G_k = 960.0 \text{ kN}$
 $P_k = 612.5 \text{ kN}$

Concrete
strength class: C 25/30

Profile: Rolled section
HE 300 B
Steel grade: S 235



Composite column

Mechanical actions during fire exposure

Accidental situation:

$$E_{dA} = E \cdot (\sum G_k + A_d + \sum \psi_{2,i} \cdot Q_{k,i})$$

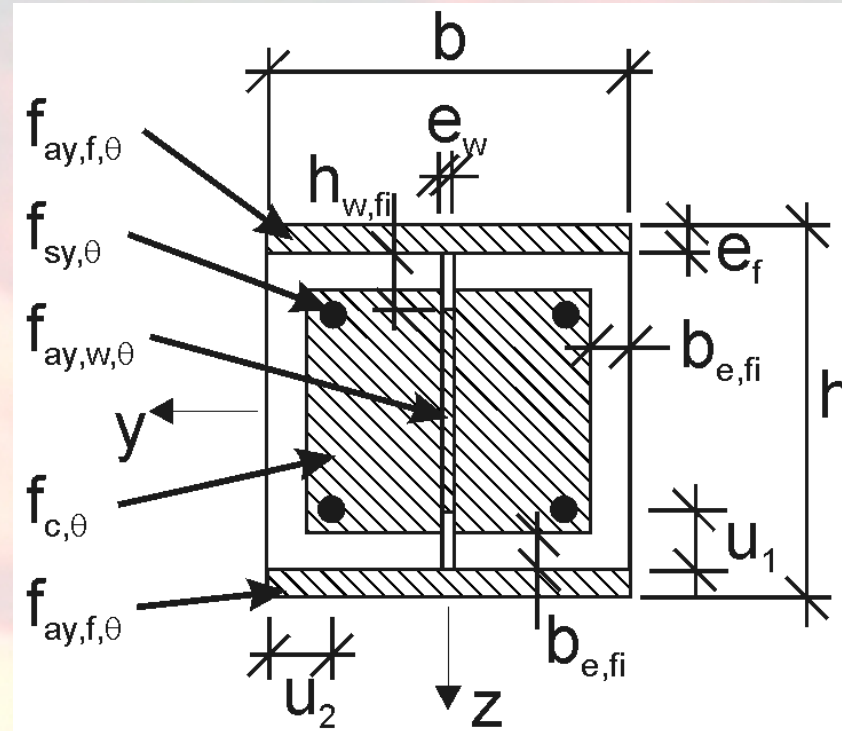
Combination factor for office areas: $\Rightarrow \psi_{2,1} = 0.3$

$$\Rightarrow N_{fi,d} = 1143.8 \text{ kN}$$

Composite column

Reduction of the cross-section in fire situation

- Flanges
 - ✧ Strength reduction
 - ✧ Stiffness reduction
- Web
 - ✧ Height reduction
 - ✧ Strength reduction
 - ✧ Stiffness reduction
- Reinforcements
 - ✧ Strength reduction
 - ✧ Stiffness reduction
- Concrete
 - ✧ Thickness reduction
 - ✧ Strength reduction
 - ✧ Stiffness reduction



Composite column

Design axial resistance and verification

- Calculation of the axial design resistance:

$$N_{fi,pl,Rd} = \sum N_{fi,pl,Rd,i} = 2659.8 \text{ kN}$$

where

$N_{fi,pl,Rd,i}$ plastic design resistances of the several parts

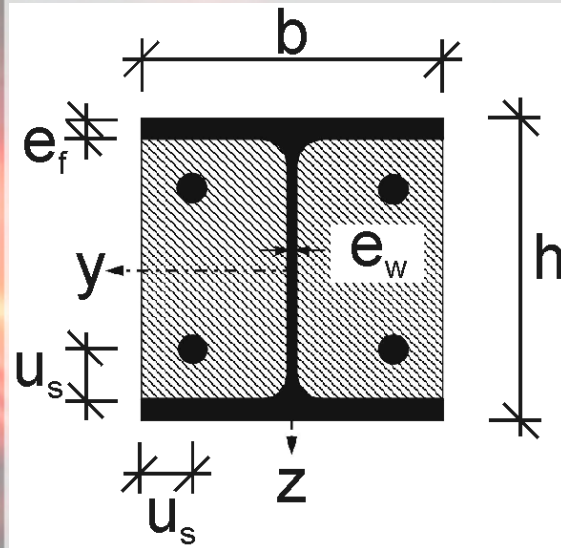
- Flexural buckling:

$$\frac{N_{fi,d}}{\chi_{z,fi} \cdot N_{fi,pl,Rd}} = 0.50 \leq 1$$

$\chi_{z,fi}$ is determined similar to example „Steel column“

Composite column

Tabulated data method



Existing parameters:

$$e_w/e_f = 0.58$$

$$b = h = 300 \text{ mm}$$

$$u_s = 50 \text{ mm}$$

$$\eta_{fi,t} = 0.28$$

$$\frac{A_s}{A_c + A_s} = 3\% \quad \text{⚡}$$

		R30	R60
	Minimum ratio of web to flange thickness e_w/e_f	0,5	0,5
1	Minimum cross-sectional dimensions for load level $\eta_{fi,t} \leq 0,28$		
1.1	minimum dimensions h and b [mm]	160	200
1.2	minimum axis distance of reinforcing bars u_s [mm]	-	50
1.3	minimum ratio of reinforcement $A_s/(A_c+A_s)$ in %	-	4