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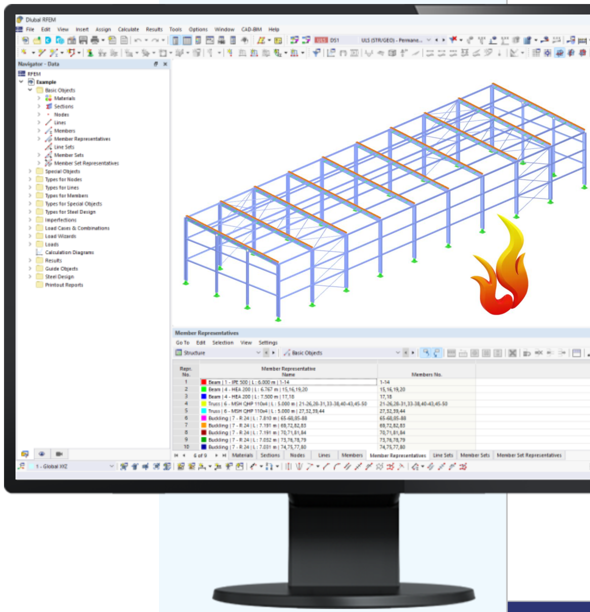
Webinar

Fire Design in Steel Structures with RFEM 6



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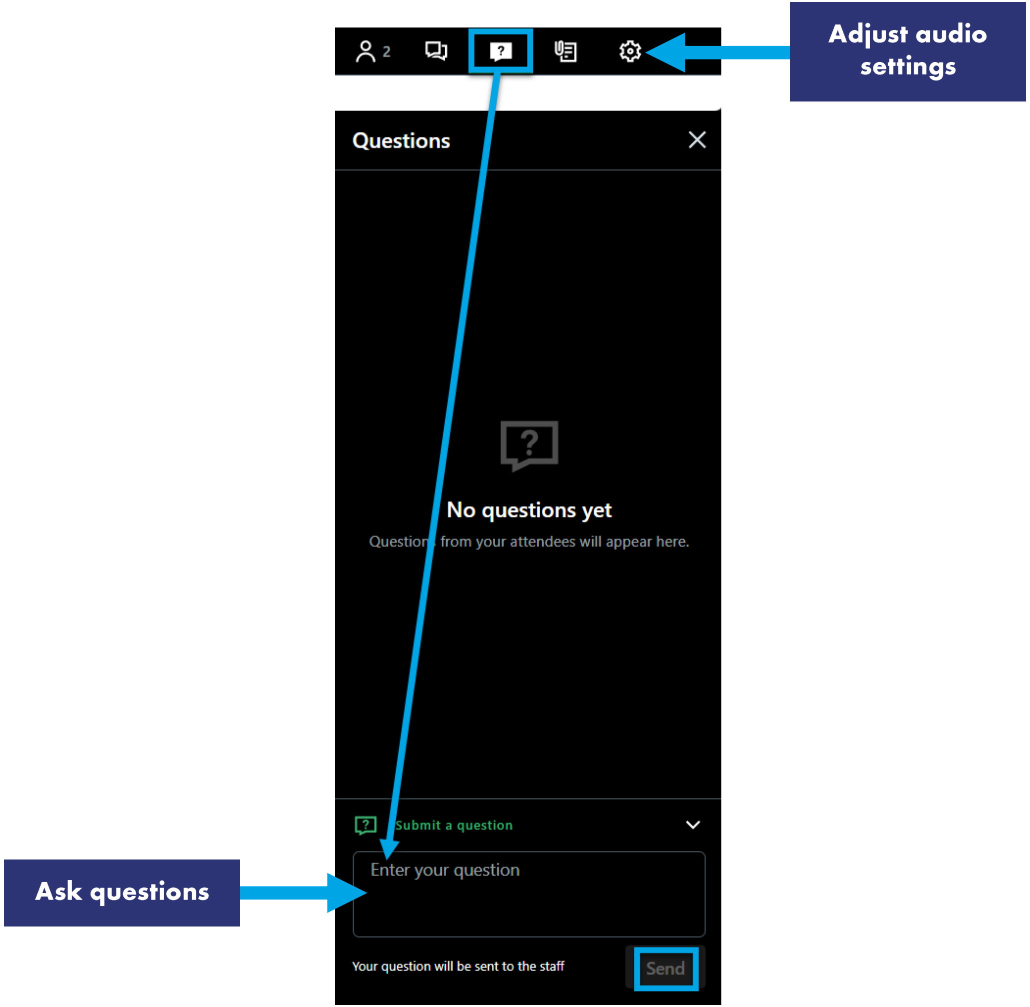

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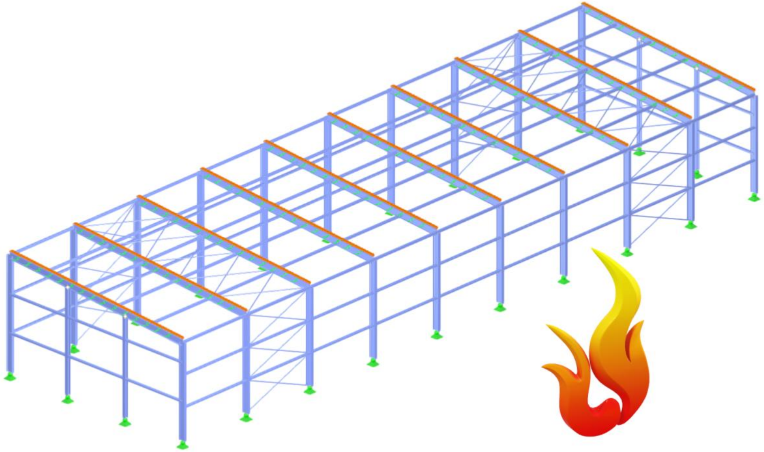

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Webinar

Basics of fire protection

Fire protection goals → Fire protection measures → Specific requirements

Example GER – MBO §14:

„Buildings must be designed in such a way that the **development** of a fire and the **spread** of **fire** and **smoke** is **prevented** and that **people** and **animals** can be **rescued** and effective **extinguishing work** can be carried out in the event of a fire."

Technical

- Fire detection systems
- Security lighting
- …

Structural

- Fire compartments
- Fire behaviour of materials
- Fire resistance of str. components
- …

Organisational

- Fire fighting
- Fire protection plans/check-ups
- …

Fire resistance requirements (GER):

Requirements acc. to function and building class

• Fire retardant	e.g.: R 30
• Highly fire retardant	e.g.: REI 60
• Fire resistant	e.g.: EI 90
• …	
↑ Requirement MBO	↑ Classification EN 13501-2

→ Member verification by analysis according to Eurocodes

Fire design according to Eurocodes

Combinatorics: EN 1990

$$E_{fi,d} = \sum_{j\geq 1} G_{k,j} + \left(\psi_{1,1} \text{ oder } \psi_{2,1}\right) \cdot Q_{k,1} + \sum_{i\geq 1} \psi_{2,i} \cdot Q_{k,i}$$

Whether the quasi-permanent value $\psi_{2,1} \cdot Q_1$ or the frequent value $\psi_{1,1} \cdot Q_1$ s to be used can be found in the National Annex of EN 1991-1-2.

Simplification:

$$E_{fi,d} = \eta_{fi} \cdot E_d$$

η_{fi} = 0,6

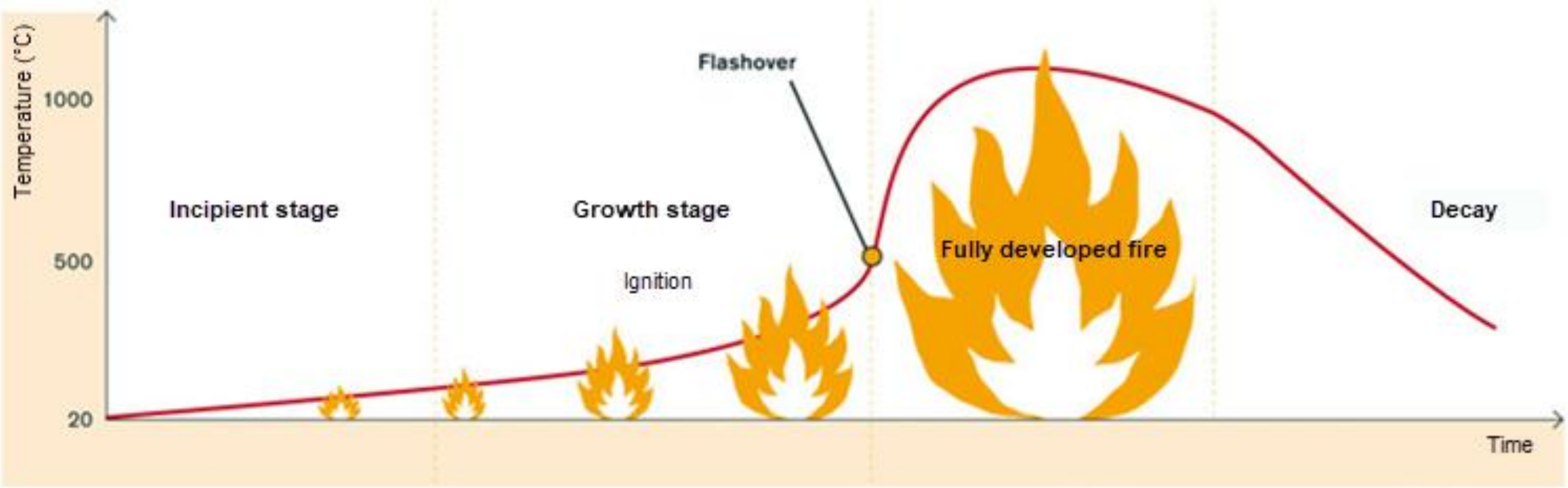
η_{fi} = 0,7 for imposed loads category E

E_d = design effect of actions for member design under normal temperature

Fire design according to Eurocodes

Combinatorics: EN 1990

Thermal actions: EN 1991-1-2

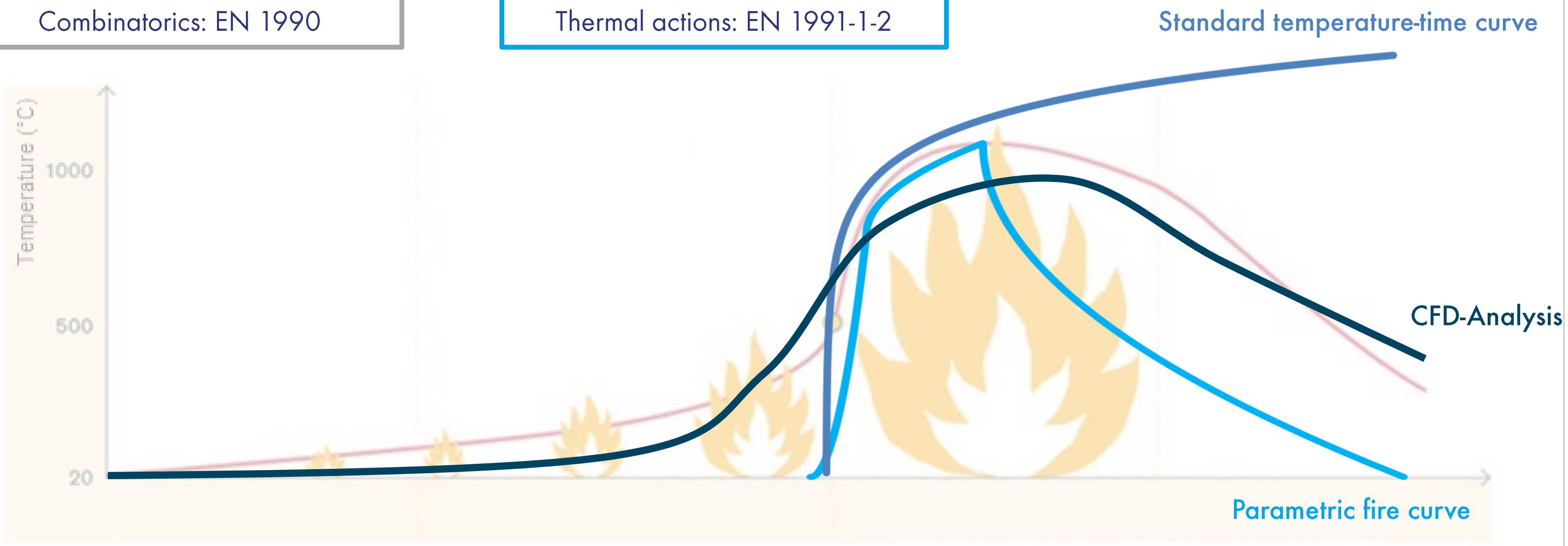


Source: TU München (TUM), Lehrstuhl für Holzbau und Baukonstruktion

Fire design according to Eurocodes

Combinatorics: EN 1990

Thermal actions: EN 1991-1-2



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Fire design according to Eurocodes

Combinatorics: EN 1990

Thermal actions: EN 1991-1-2

Structural design: EN 1993-1-2

Simple — Complexity — Complex

Conservative — Accuracy — Realistic

Level 1: Tabulated design data

- Not available for the design of steel structures (EN 1993-1-2)

Level 2: Simplified design methods

- Thermal actions given by nominal fire curves (nominal fire conditions)
- Design of **Members** under prescribed rules given in EN 1993-1-2
- Verification can be done **Resistance based** or **temperature based**

Level 3: Advanced design methods

- Thermal actions based on parametric fire curves, zone-models, CFD, ... (natural fire conditions)
- Design of **members/substructures/structures** using „suitable“ and validated thermal + mechanical analysis models
- Validity of the assumptions made must be proven on a case-specific basis and requires a high level of expertise

Ambient temperature development

Standard temperature-time curve

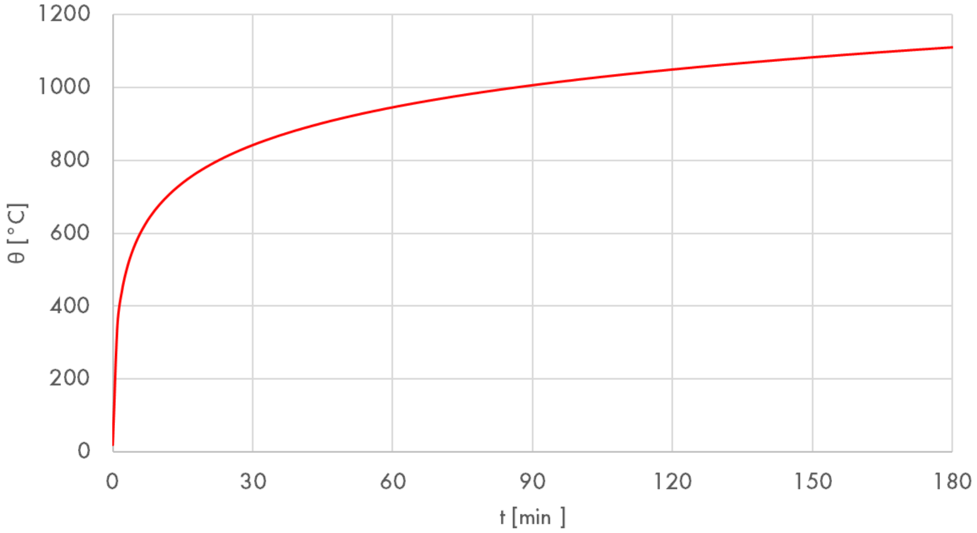
Was originally introduced for standardized fire tests on structural elements

EN 1991-1-2 equation (3.4)

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

θ_g gas temperature in the fire compartment [°C]

t time [min]



Steel temperature development

Net heat flux received by the heated surface according to EN 1991-1-2

- Net heat flux from Convection (c) and Radiation (r)

$$\dot{h}_{net} = \dot{h}_{net,c} + \dot{h}_{net,r}$$

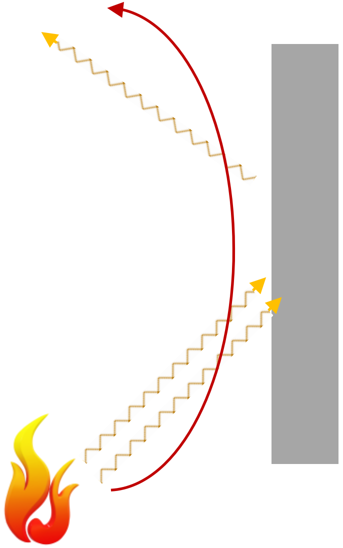
$$\dot{h}_{net} = \alpha_c\left(\theta_g - \theta_m\right) + \Phi \cdot \varepsilon_m \cdot \varepsilon_f \cdot \sigma \cdot \left((\theta_r + 273)^4 - (\theta_m + 273)^4\right)$$

ambient temp. ~ member temp. ~ambient temp. ~ member temp.

Steel temperature development according to EN 1993-1-2

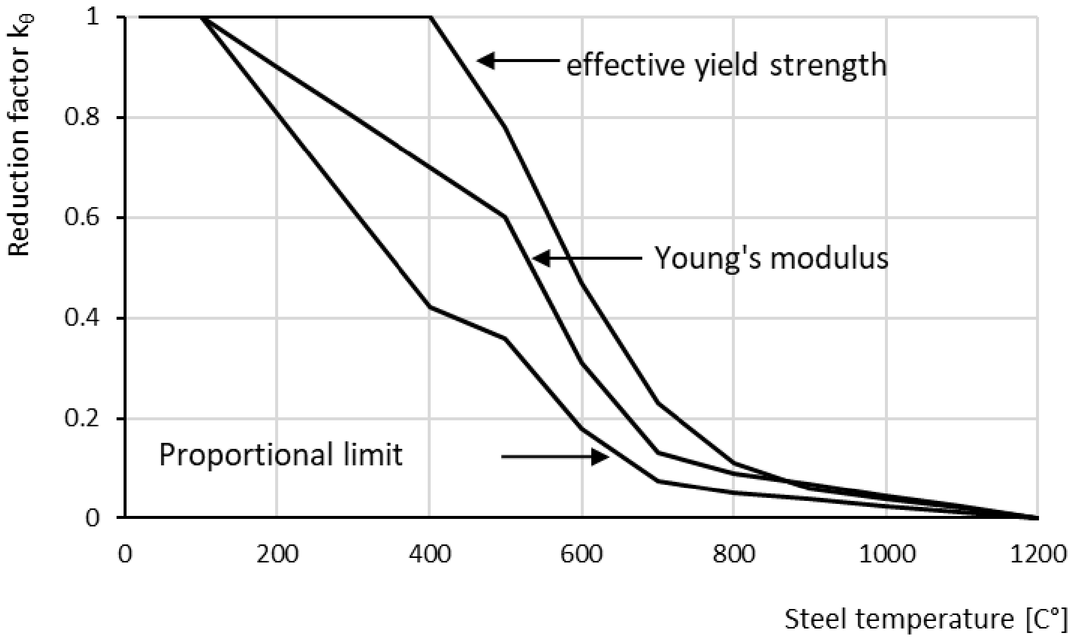
- Unprotected internal steelwork

$$\Delta\theta_{a,t} = k_{sh}\frac{A_m / V}{c_a \cdot \rho_a}\dot{h}_{net} \cdot \Delta t$$



Properties of steel under elevated temperature

Reduction of material properties according to EN 1993-1-2



Steel temperature development

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$$\dot{h}_{net} = \underbrace{\dot{h}_{net,c}}_{} + \underbrace{\dot{h}_{net,r}}_{}$$

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Steel temperature development according to EN 1993-1-2

- Unprotected internal steelwork

$$\Delta\theta_{a,t} = k_{sh}\frac{A_m / V}{c_a \cdot \rho_a}\dot{h}_{net} \cdot \Delta t$$

Steel temperature development

Steel temperature development according to EN 1993-1-2

- Unprotected internal steelwork

Coefficient of heat transfer

Stephan Boltzmann constant

$$\Delta\theta_{a,t} = k_{sh} \frac{A_m / V}{c_a \cdot \rho_a} \left[\alpha_c \left(\theta_g - \theta_a\right) + \Phi \cdot \varepsilon_m \cdot \varepsilon_f \cdot \sigma \cdot \left(\left(\theta_r + 273\right)^4 - \left(\theta_a + 273\right)^4\right)\right] \cdot \Delta t$$

Emissivity of fire

Specific heat of steel (temperature-dependent)

Density of steel

Configuration factor

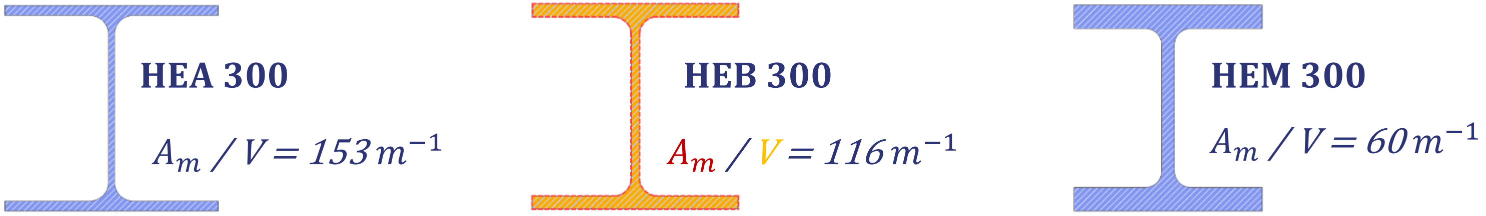
Steel temperature development

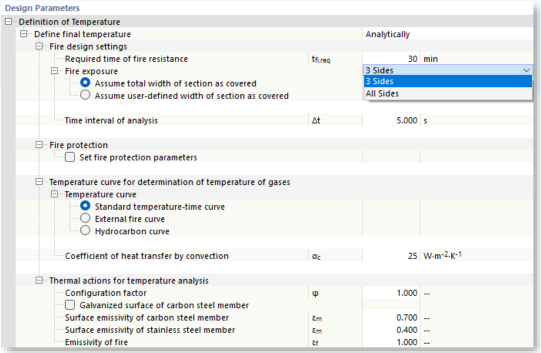
Steel temperature development according to EN 1993-1-2

- Unprotected internal steelwork

Section factor
(surface/volume)

$$\Delta\theta_{a,t} = k_{sh} \frac{A_m / V}{c_a \cdot \rho_a} \left[\alpha_c \left(\theta_g - \theta_a\right) + \Phi \cdot \varepsilon_m \cdot \varepsilon_f \cdot \sigma \cdot \left((\theta_r + 273)^4 - (\theta_a + 273)^4\right)\right] \cdot \Delta t$$





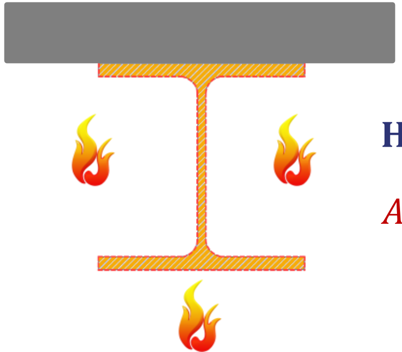
Steel temperature development

Steel temperature development according to EN 1993-1-2

- Unprotected internal steelwork

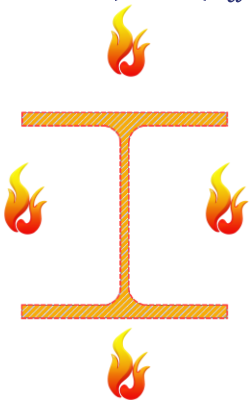
Section factor (surface/volume)

$$\Delta\theta_{a,t} = k_{sh} \frac{A_m / V}{c_a \cdot \rho_a} \left[\alpha_c \left(\theta_g - \theta_a\right) + \Phi \cdot \varepsilon_m \cdot \varepsilon_f \cdot \sigma \cdot \left((\theta_r + 273)^4 - (\theta_a + 273)^4\right)\right] \cdot \Delta t$$



HEB 300, 3 side exposure

$A_m / V = 96\, m^{-1}$



HEB 300, 4 side exposure

$A_m / V = 116\, m^{-1}$

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Steel temperature development

Steel temperature development according to EN 1993-1-2

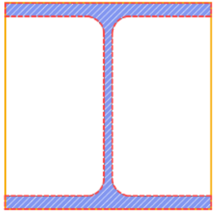
- Unprotected internal steelwork

$$\Delta\theta_{a,t} = k_{sh} \frac{A_m / V}{c_a \cdot \rho_a} \left[\alpha_c \left(\theta_g - \theta_a\right) + \Phi \cdot \varepsilon_m \cdot \varepsilon_f \cdot \sigma \cdot \left((\theta_r + 273)^4 - (\theta_a + 273)^4\right)\right] \cdot \Delta t$$

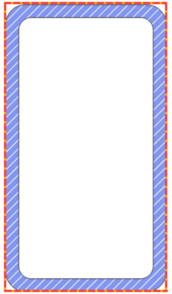
Correction factor
Shadowing effect

Delayed heating for branched sections:

$$k_{sh} = \begin{cases} 0{,}9 * \dfrac{[A_m / V]_b}{A_m / V} & \text{for I-sections} \\ \dfrac{[A_m / V]_b}{A_m / V} & \text{otherwise} \end{cases}$$



$$\frac{[A_m]_b}{A_m} < 1$$

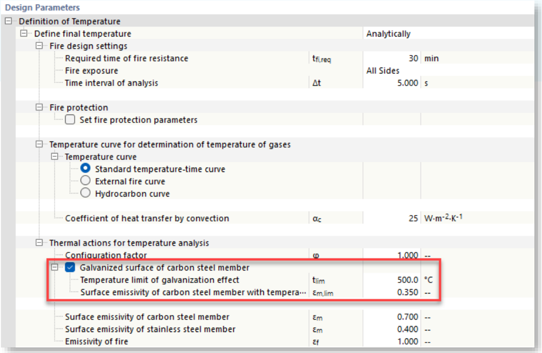


$$\frac{[A_m]_b}{A_m} = 1$$

Steel temperature development

Steel temperature development according to EN 1993-1-2

- Unprotected internal steelwork



Surface emissivity of the member

$$\Delta\theta_{a,t} = k_{sh} \frac{A_m / V}{c_a \cdot \rho_a} \left[\alpha_c \left(\theta_g - \theta_a\right) + \Phi \cdot \varepsilon_m \cdot \varepsilon_f \cdot \sigma \cdot \left(\left(\theta_r + 273\right)^4 - \left(\theta_a + 273\right)^4\right)\right] \cdot \Delta t$$

	ε_m (t ≤ 500 °C)	ε_m (t > 500 °C)
Carbon steel	0,7	
Stainless steel	0,4	
HDG (Kat. A / B)*	0,35	0,7

*prEN 1993-1-2: 2022-03

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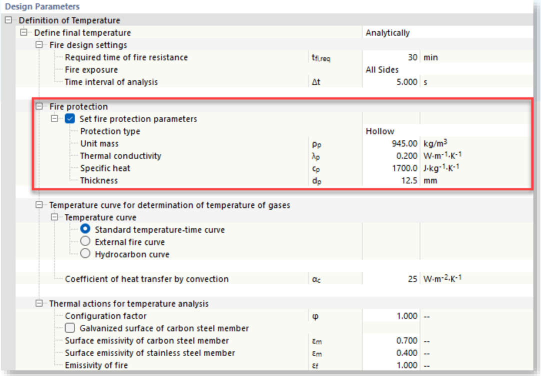


Design Parameters

Definition of Temperature			
Define final temperature		Analytically	
Fire design settings			
Required time of fire resistance	$t_{fi,req}$	30	min
Fire exposure		All Sides	
Time interval of analysis	Δt	5.000	s
Fire protection			
☑ Set fire protection parameters			
Protection type		Hollow	
Unit mass	ρ_p	945.00	kg/m^3
Thermal conductivity	λ_p	0.200	$W \cdot m^{-1} \cdot K^{-1}$
Specific heat	c_p	1700.0	$J \cdot kg^{-1} \cdot K^{-1}$
Thickness	d_p	12.5	mm
Temperature curve for determination of temperature of gases			
Temperature curve			
◉ Standard temperature-time curve			
○ External fire curve			
○ Hydrocarbon curve			
Coefficient of heat transfer by convection	α_c	25	$W \cdot m^{-2} \cdot K^{-1}$
Thermal actions for temperature analysis			
Configuration factor	φ	1.000	--
☐ Galvanized surface of carbon steel member			
Surface emissivity of carbon steel member	ε_m	0.700	--
Surface emissivity of stainless steel member	ε_m	0.400	--
Emissivity of fire	ε_f	1.000	--

Steel temperature development

Steel temperature development according to EN 1993-1-2

- Internal steelwork insulated by fire protection material

Thermal conductivity of fire protection system

Specific heat of fire protection system

Density of fire protection system

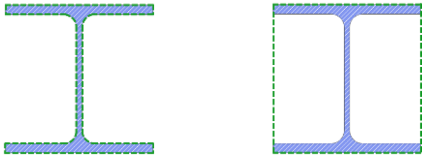
$$\Delta\theta_{a,t} = \frac{\lambda_p}{d_p} \cdot \frac{A_p / V}{c_a \cdot \rho_a} \frac{(\theta_g - \theta_a)}{(1 + \phi/3)} \cdot \Delta t - \left(e^{\phi/10} - 1\right) \cdot \Delta\theta_{g,t}$$

with

$$\phi = \frac{c_p \cdot \rho_p}{c_a \cdot \rho_a} d_p \, A_p / V$$

Thickness of fire protection system

Section factor based on perimeter or encasement



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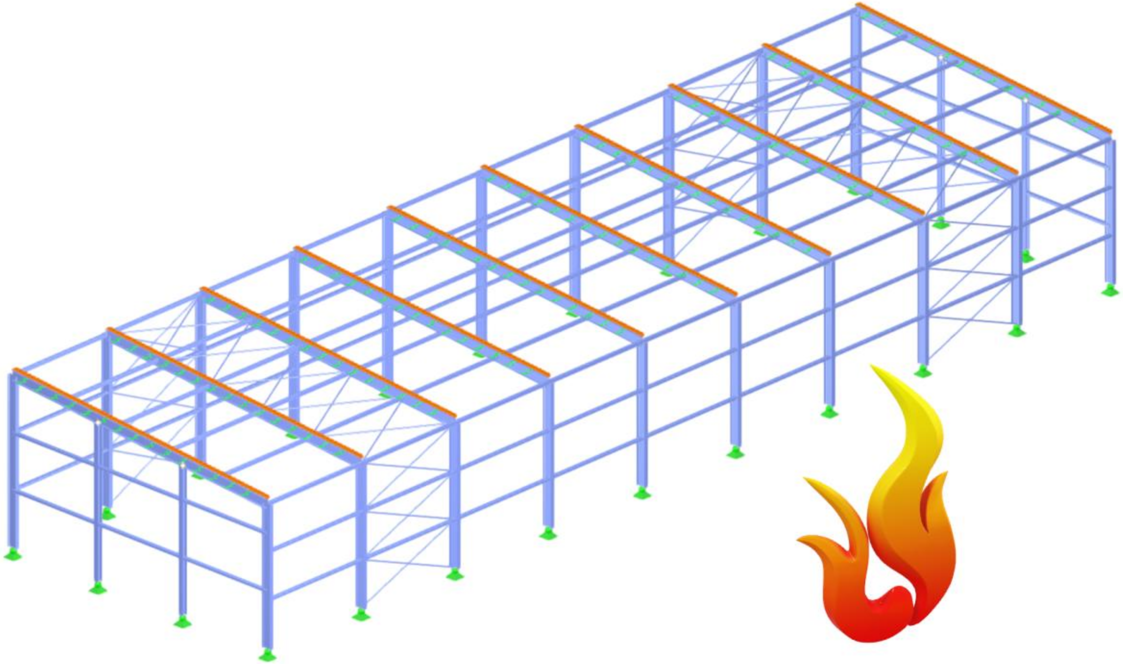
FAQs Fire design

- How should we consider indirect actions due to thermal expansion/deformation in the analysis?



Indirect actions due to thermal deformation

Generally, indirect actions must be taken into account in fire design, but:

Exception EN 1991-1-2, Section 4.1 „General“:

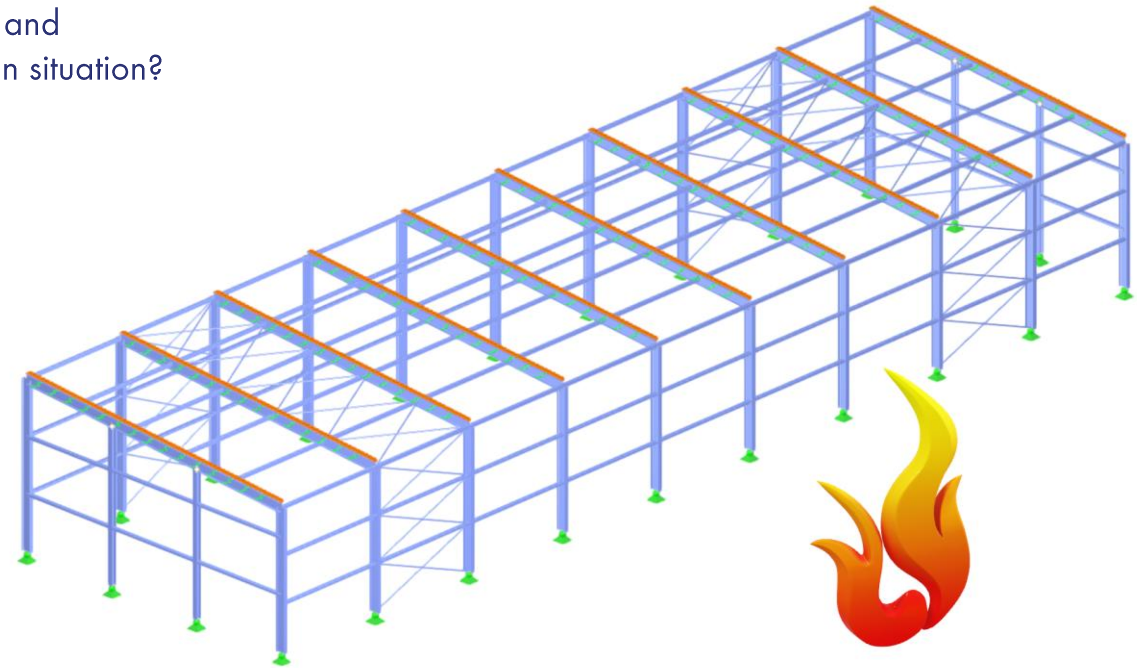
- (4) „Indirect actions from adjacent members should not be considered when fire safety requirements refer to members under standard fire conditions.“

Exception EN 1993-1-2, Section 2.4.2 „Member analysis“:

- (4) „The effects of thermal deformations resulting from thermal gradients across the cross-section shall be considered. The effects of axial or in-plane thermal expansions may be neglected.“

FAQs Fire design

- How should we consider indirect actions due to thermal expansion/deformation in the analysis?
- How can we modify buckling lengths and boundary conditions for the fire design situation?



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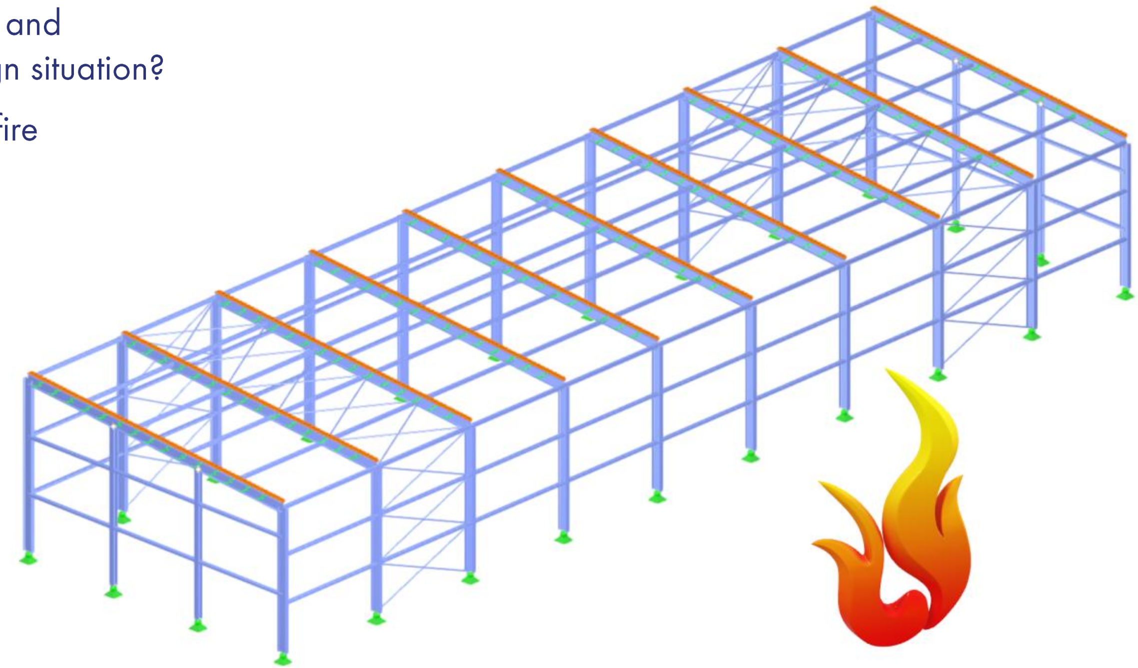
- (4) „Indirect actions from adjacent members should not be considered when fire safety requirements refer to members under standard fire conditions.“

Exception EN 1993-1-2, Section 2.4.2 „Member analysis“:

- (4) „The effects of thermal deformations resulting from thermal gradients across the cross-section shall be considered. The effects of axial or in-plane thermal expansions may be neglected.“
- (5) „The kinematic boundary conditions at supports and ends of members, applicable at time $t = 0$, may be assumed to remain unchanged throughout the fire exposure.“

FAQs Fire design

- How should we consider indirect actions due to thermal expansion/deformation in the analysis?
- How can we modify buckling lengths and boundary conditions for the fire design situation?
- How can we verify steel joints under fire conditions?



Fire design of steel joints

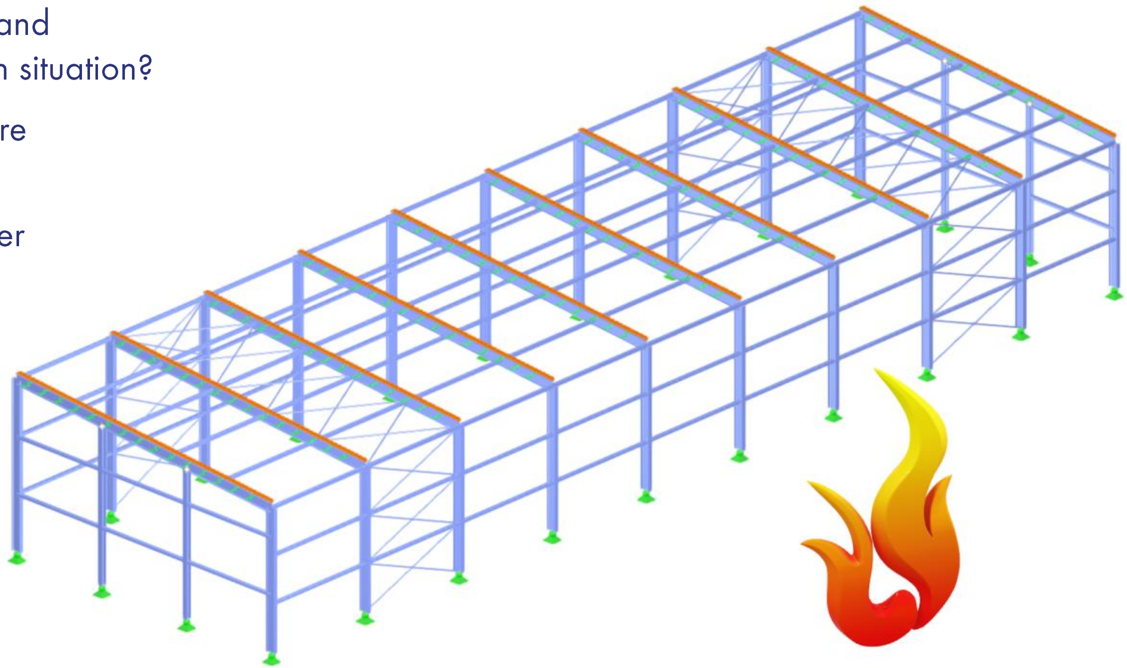
- Experience shows that joints are often unproblematic. This is mainly due to the local mass concentration caused by welded-in sheets/stiffeners and bolts. The joint usually heats up much less than the connected members.

- According to EN 1993-1-2, Section 4.2.1 (6) verification of joints can be considered settled, if:
  - $\left(\frac{d_f}{\lambda_f}\right)_{connection} \geq \left(\frac{d_f}{\lambda_f}\right)_{member,min}$
  - $\left(\frac{E_d}{R_d}\right)_{connection,20°} \leq \left(\frac{E_d}{R_d}\right)_{member,min,20°}$

- Alternatively, verification can be carried out according to EN 1993-1-2, Annex D:
  - „Hot" design with reduced resistance of bolts and welds
  - Temperature of the joint can be based on the temperature of the connected members

FAQs Fire design

- How should we consider indirect actions due to thermal expansion/deformation in the analysis?
- How can we modify buckling lengths and boundary conditions for the fire design situation?
- How can we verify steel joints under fire conditions?
- How can I calculate the critical member temperature?



Summary

- Simple fire design check on member level under standard fire conditions is possible as part of steel design in RFEM 6 (and RSTAB 9)
- Member analysis design checks according to EN 1993-1-2 are very similar to the checks given in EN 1993-1-1 for normal temperature but incorporate reduction factors to penalize material degradation at elevated temperature
- Choosing a suitable cross-section and leveraging the advantages of hot-dip galvanizing, R 30 requirements can be met in some cases even without special fire protection measures
- Higher fire resistance requirements can also be met with suitable measures (plaster / encasement)
- Indirect actions due to thermal expansion/deformation can be estimated via temperature-dependent material and additional temperature load
- Modification of buckling lengths or boundary conditions for member stability analysis under fire conditions is possible via construction stages / structure modifications
- The fire resistance of joints can often be verified in a simplified manner

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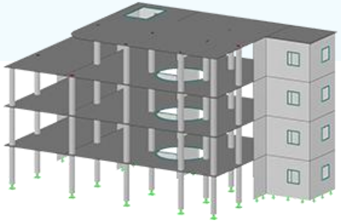

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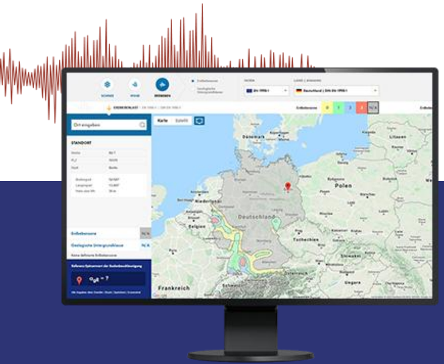

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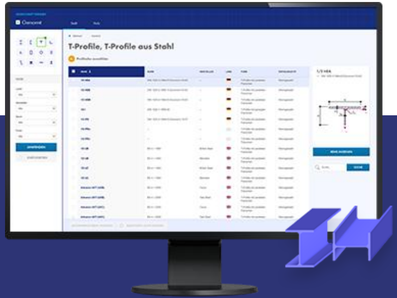

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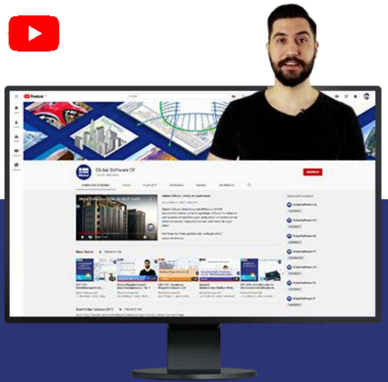

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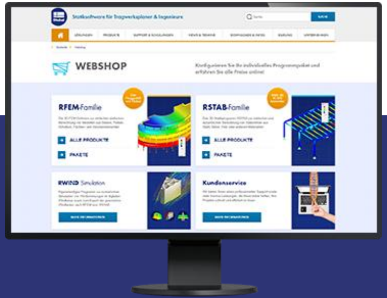

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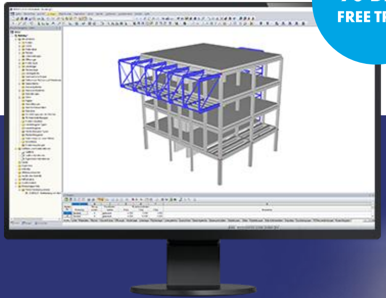

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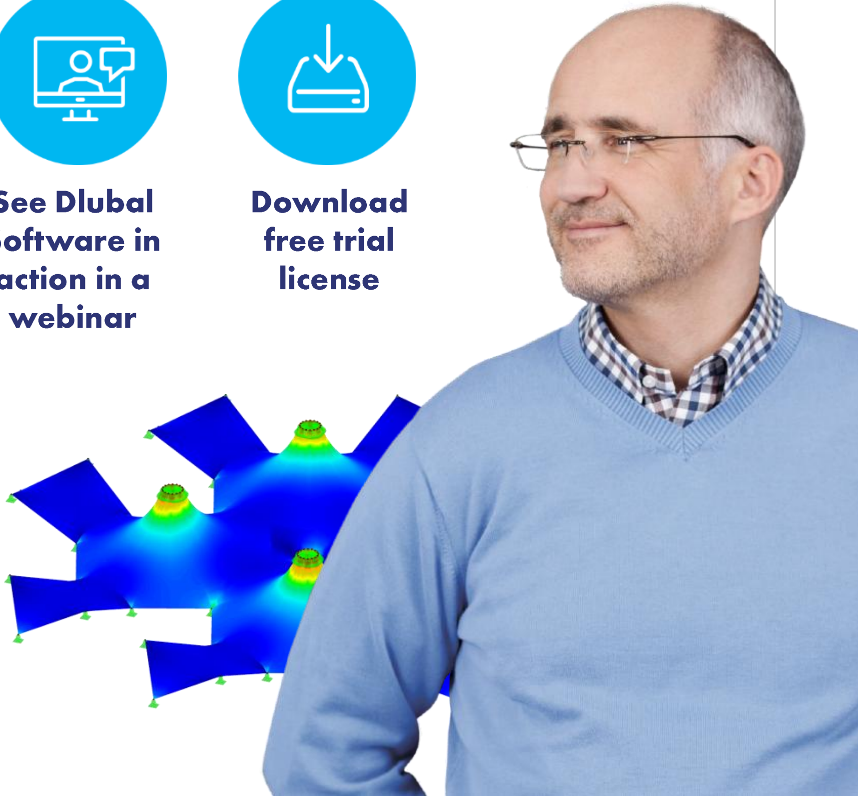

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