

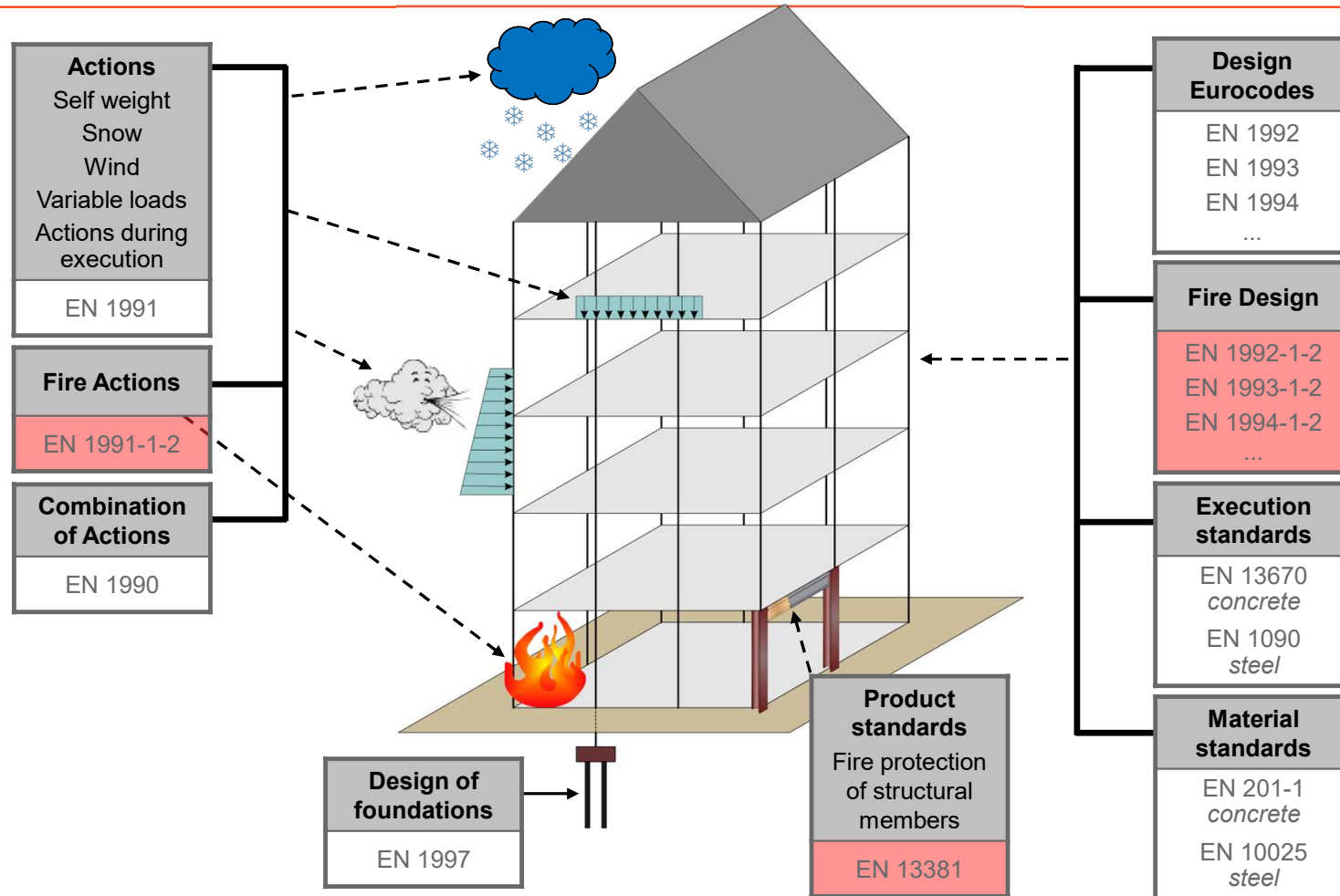


La prestazione di resistenza al fuoco negli
Eurocodici di seconda generazione

New generation of Eurocodes fire part

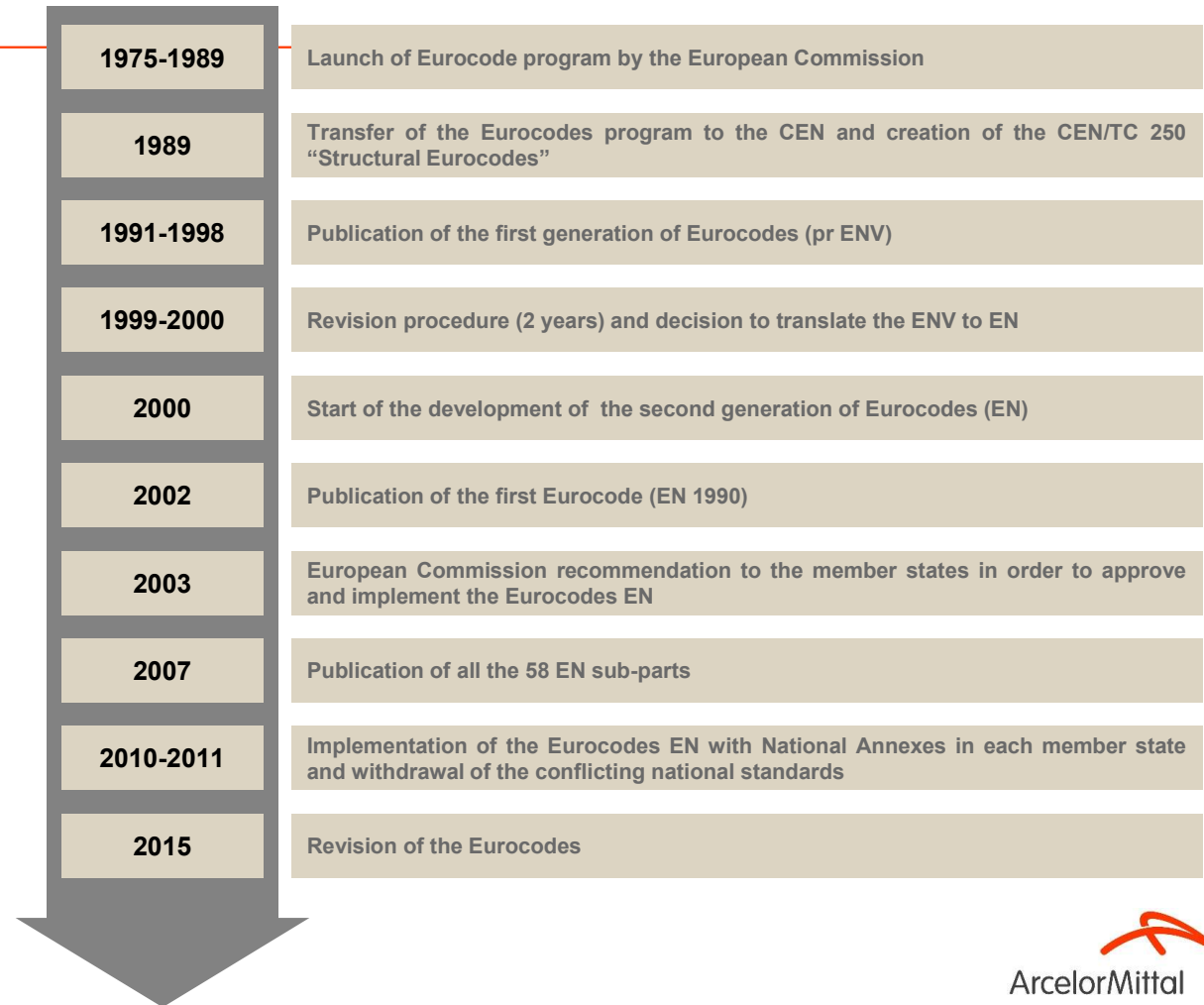
- Introduction
 - New Eurocodes : what is new and when?
 - Fire : what does it mean?
 - Requirements
- Steel structures: Eurocode 3 fire part : EN 1993-1-2
 - Main relevant improvements:
 - Extension to High strength steels,
 - Normative annexes for Stainless steels and joints; new rules for class 4 sections in the main text
 - New annex for cellular beams
- Composite Steel/Concrete structures: Eurocode 4 fire part : EN 1994-1-2
 - Overview of the changes
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 - Concrete-filled Tubular Sections
 - Composite Slim Floor Beams
 - Membrane Effect
 - Cellular Beams
- Actions in case of fire : Eurocode 1 fire part : EN 1991-1-2
 - Natural fire

New Eurocodes : what is new and when?



New Eurocodes : what is new and when?

Eurocode History



New Eurocodes : what is new and when?

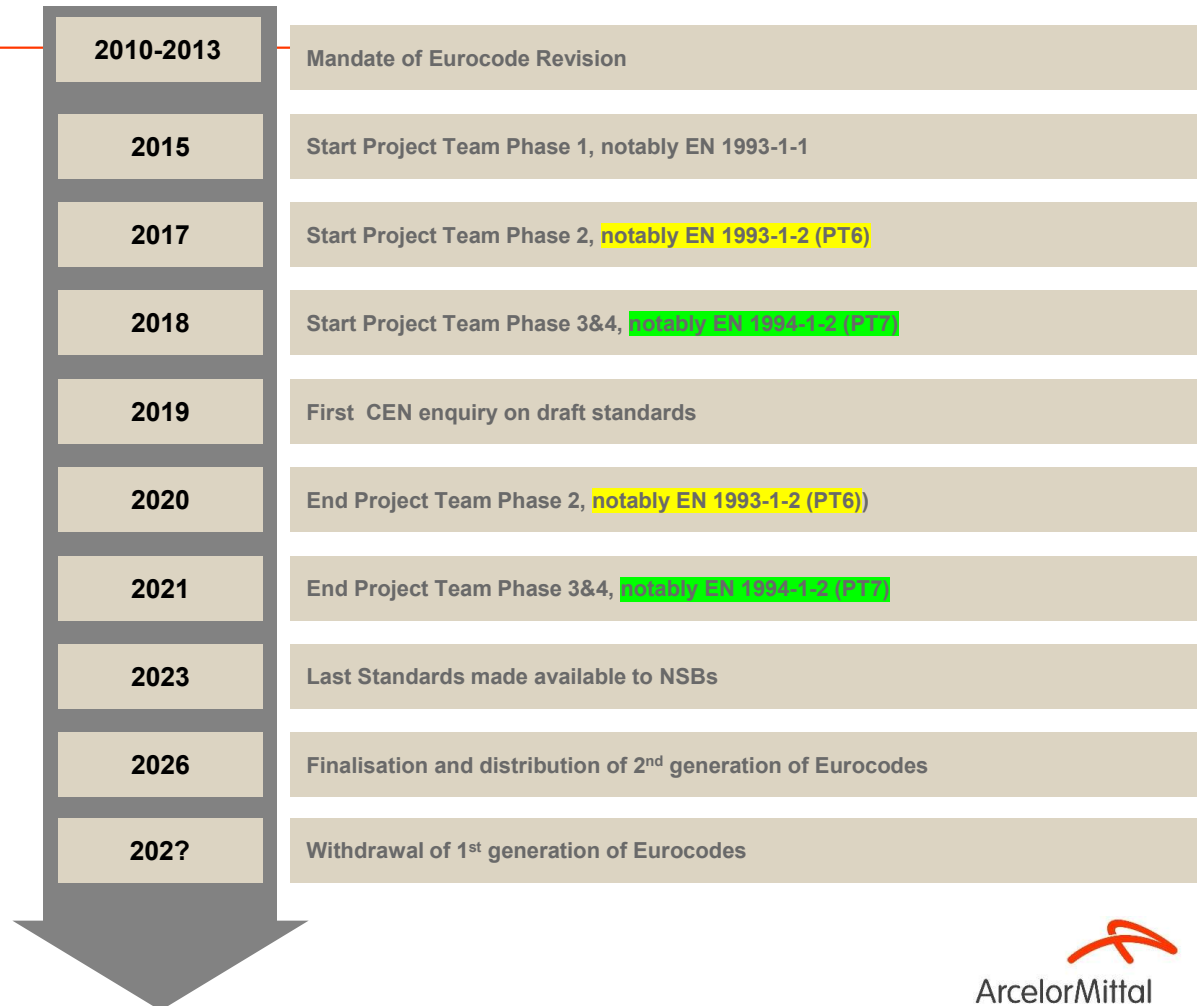
Eurocode Revision

Time line



François Hanus:

- Member of TC250/SC4/PT2 (2015 – 2018)
- Member of TC250/SC3/PT6 (2017 – 2020)
- Chairman of TC250/SC4/PT7 (2018 – 2021)
- Convenor of TC250/SC4/AHG2 (2023 - ...)



New Eurocodes : what is new and when?

Eurocode 3

Present version provides

- Fire design rules for steel up to S460
- Thermal and mechanical properties for Carbon and stainless steels
- Method to calculate steel temperature development
- Methods to assess fire resistance through simple calculation model for carbon steel
- Give principles for advanced calculation models
- Give some informative annexes for external steel structures, stainless steel, joints and class 4 sections

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 1993-1-2

April 2005

ICS 13.220.50; 91.010.30; 91.080.10

Supersedes ENV 1993-1-2:1995

English version

Eurocode 3: Design of steel structures - Part 1-2: General rules -
Structural fire design

Eurocode 3: Calcul des structures en acier - Partie 1-2:
Règles générales - Calcul du comportement au feu

Eurocode 3: Bemessung und Konstruktion von Stahlbauten
- Teil 1-2: Allgemeine Regeln - Tragwerksbemessung für
den Brandfall

This European Standard was approved by CEN on 23 April 2004.

Revision: →

- Extension to High strength steels,
- New rules for class 4 sections in the main text
- Normative annexes for Stainless steels and joints;
- New annex for cellular beams
- Emissivity of HDG steel

New Eurocodes : what is new and when?

Eurocode 4: Present version provides

- Fire design rules for structural steel up to S460 and concrete up to C50/60, rebars acc. to EN 10080
- Thermal and mechanical properties for structural steel, rebars and concrete
- Tabulated data to calculate fire resistance of
 - composite beam with partially encased and
 - composite column with partially or fully encased sections
 - Composite columns made of concrete filled hollow sections
- Simple Calculation Models for
 - Composite slabs
 - Composite beams comprising steel beams with no concrete encasement
 - Composite beams comprising steel beams with partial concrete encasement
 - Composite columns - Steel sections with partial concrete encasement
 - Composite columns - Concrete filled hollow sections

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 1994-1-2

August 2005

ICS 13.220.50; 91.010.30; 91.080.10; 91.080.40

Supersedes ENV 1994-1-2:1994

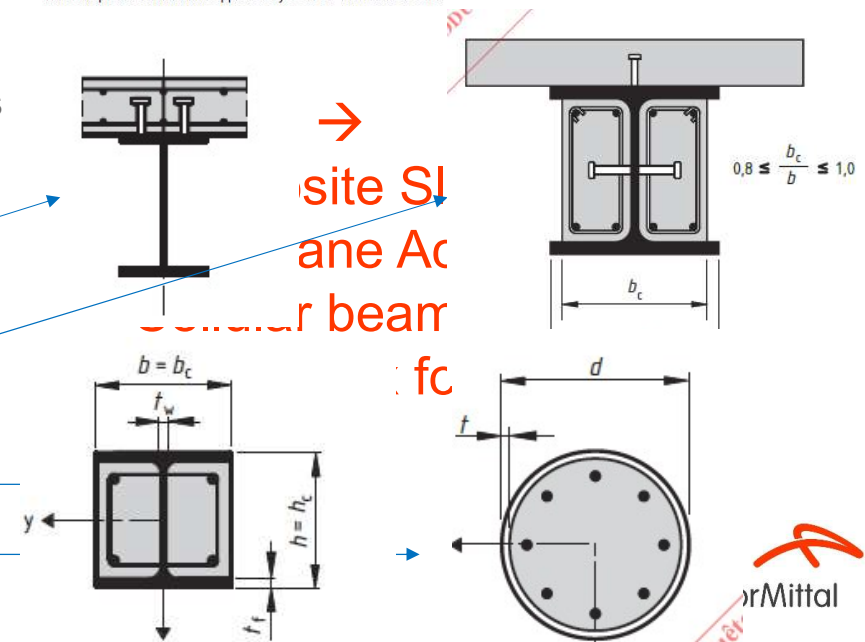
English Version

Eurocode 4 - Design of composite steel and concrete structures
- Part 1-2: General rules - Structural fire design

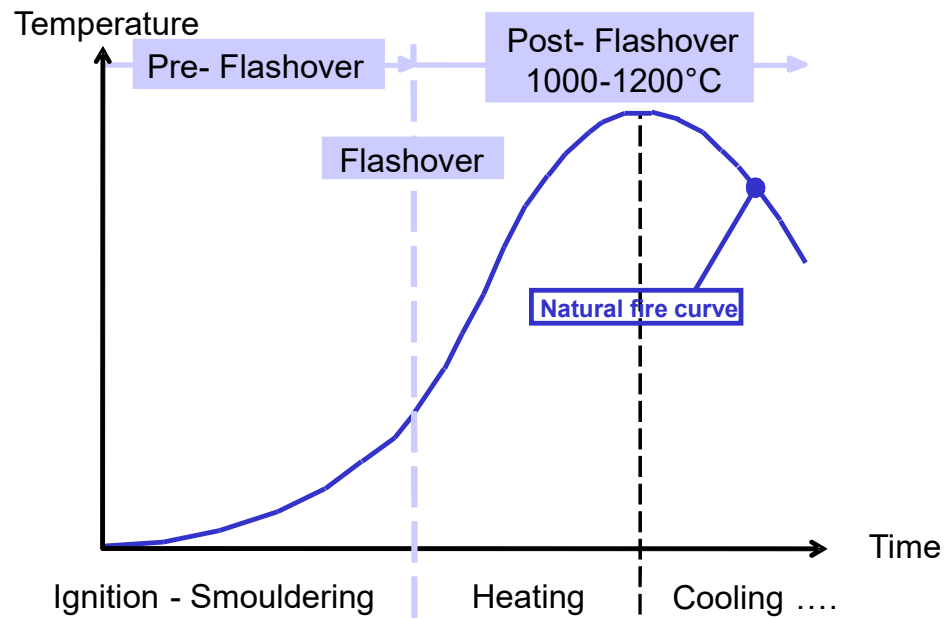
Eurocode 4 - Calcul des structures mixtes acier-béton -
Partie 1-2: Règles générales - Calcul du comportement au feu

Eurocode 4 - Bemessung und Konstruktion von Verbundtragwerken aus Stahl und Beton - Teil 1-2: Allgemeine Regeln Tragwerksbemessung im Brandfall

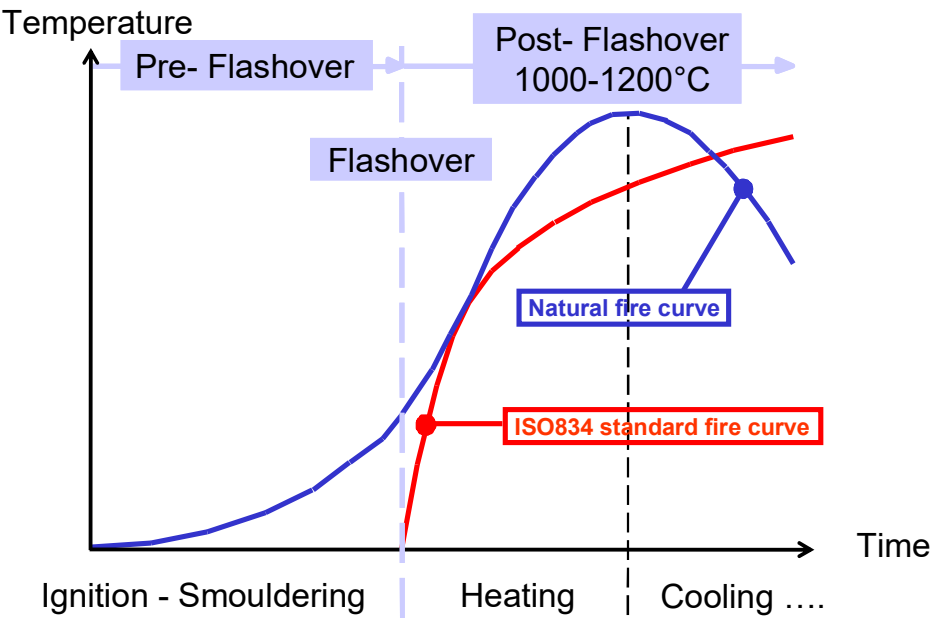
This European Standard was approved by CEN on 4 November 2004.



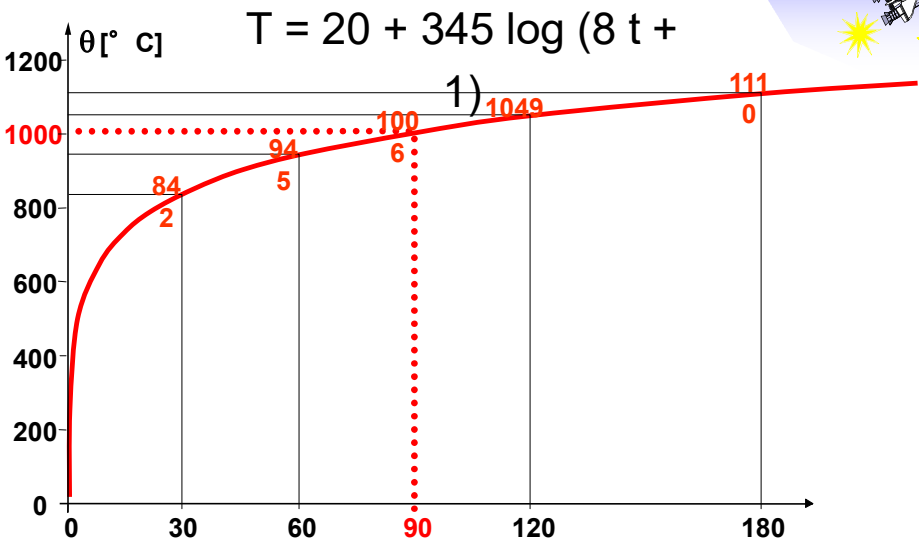
Fire : what does it mean?



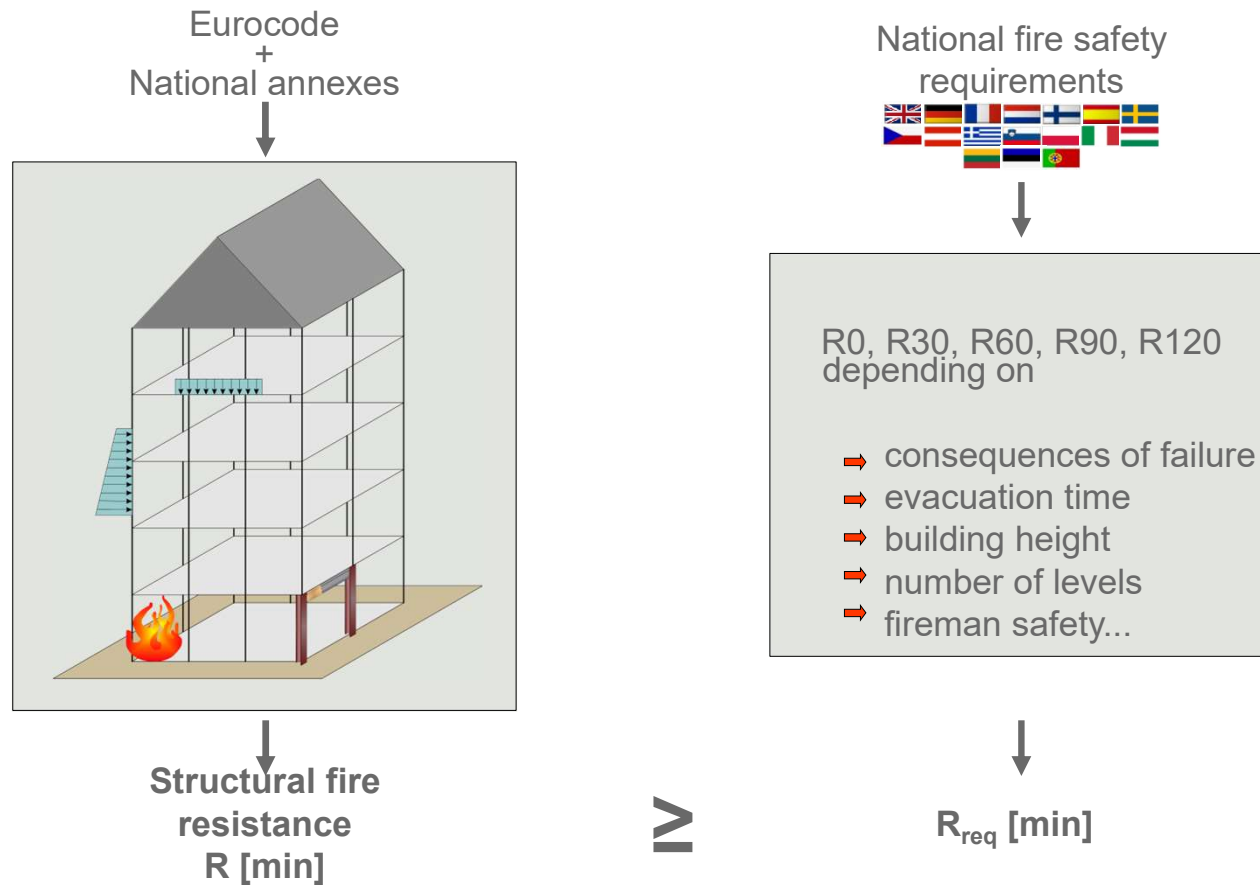
Fire : what does it mean?



ISO-834



Structural Fire safety Requirements



New generation of Eurocodes fire part

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Overview of the changes: main relevant improvements: High strength steels (S460M or S500)

Scope of EN 1993-1-2
Extended to S700
Applicable for Structural steel
listed in Table 5.1 of EN 1993-1-1
and Table 5.2 for cold forming.



Rem: In case of Natural fire
including cooling phase, material
laws valid up to S500
First amendment currently under
discussion

Steel grade ^a	Nominal thickness of the element			
	t mm			
	t ≤ 40 mm		40 mm < t ≤ 80 mm	
	f _y N/mm ²	f _u N/mm ²	f _y N/mm ²	f _u N/mm ²
S235	235	360	215	360
S275	275	390	245	370
S355	355	490	325	470
S420	420	510	390	490
S460	460	540	410	510
S500	500	580	450	580
S550	550	600	500	600
S600	600	650	550	650
S620	620	700	560	660
S650	650	700	-	-
S690	690	770	630	710
S700	700	750	-	-

^a Principal symbols in EN 10027-1.

Table 5.1 of EN 1993-1-1

Overview of the changes: main relevant improvements: Reduced emissivity for Hot-Dip Galvanised Steels

Table 5.1 — Surface emissivity of different types of steel

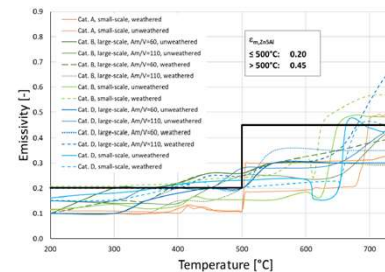
Type of steel	$\varepsilon_m (\leq 500^\circ\text{C})$	$\varepsilon_m (> 500^\circ\text{C})$
Carbon steel	0,7	
HDG steel ^a	0,35	0,7
^a Steel that has been hot-dip galvanized according to EN ISO 1461 and with steel composition according to Category A or B of EN ISO 14713-2:2020, Table 1.		

Table 5.1 of prEN 1993-1-2 and prEN 1994-1-2

Rules valid for any steel grade
Not valid in case of duplex systems
New researches still ongoing

Recent tests (2024)

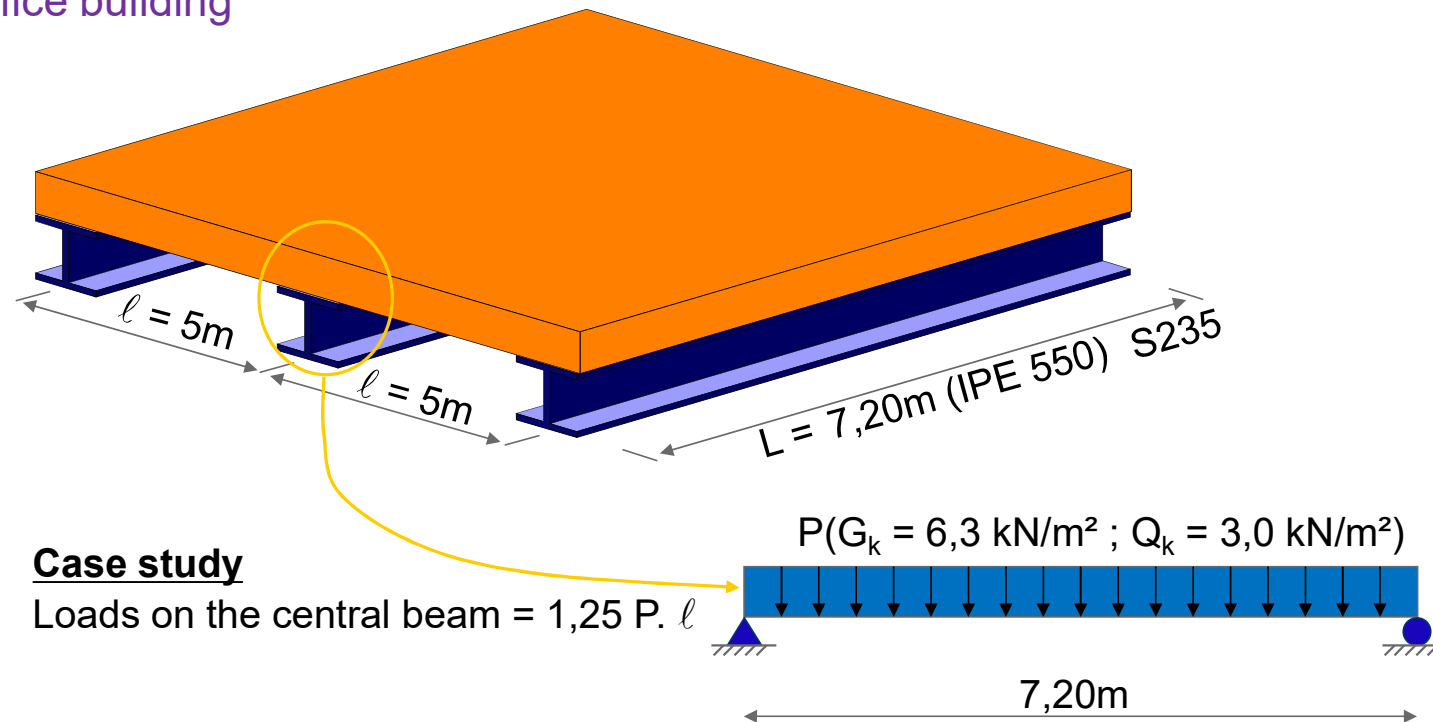
Summary of all emissivities of Zn5Al hot-dip galvanized specimens



Source : M. Mensinger, TU München

Benefit of High strength steels – R30 steel structure without any additional passive fire protection

Example: office building



Case study

Loads on the central beam = $1,25 P \cdot \ell$

Benefit of High strength steels – R30 steel structure without any additional passive fire protection

Critical temperature method: 7.5 of prEN 1993-1-2:2021 (E)

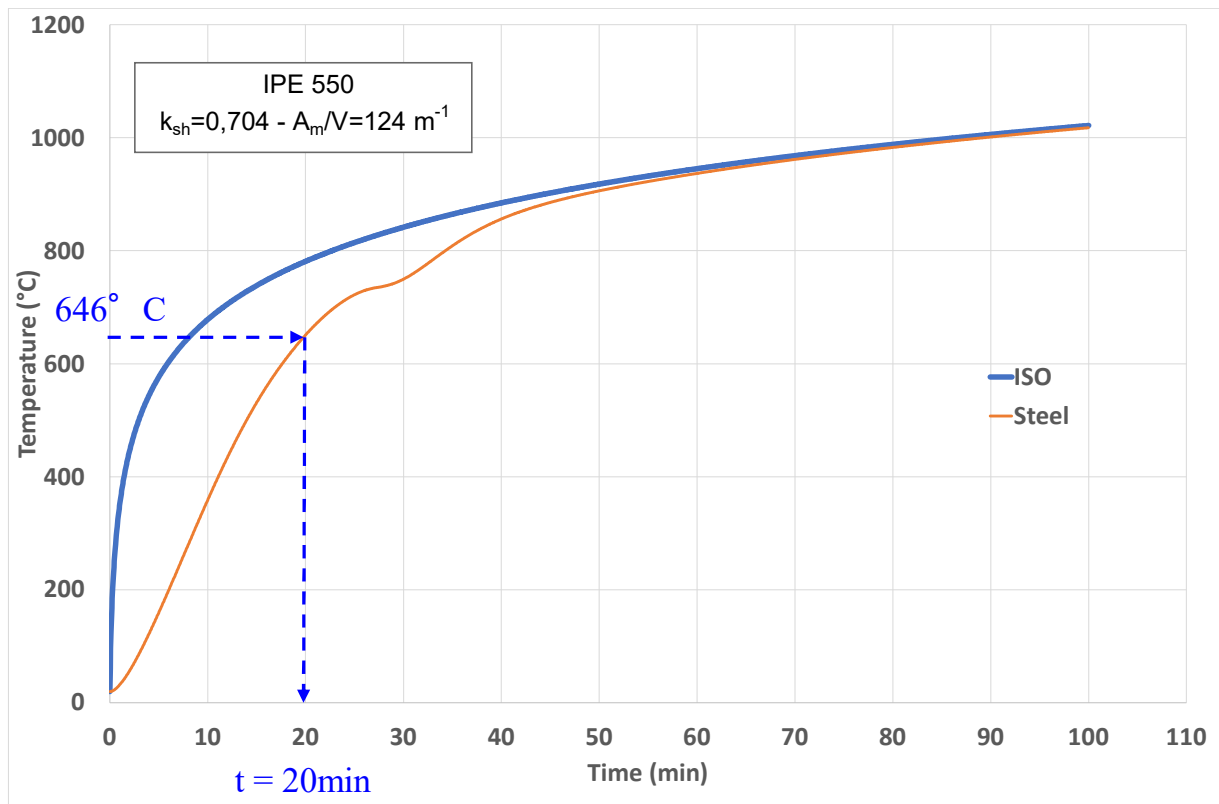
$$\mu_0 = \frac{M_{f\dot{i},Ed}}{M_{f\dot{i},0,Rd}} \quad \text{avec} \quad M_{f\dot{i},0,Rd} = M_{f\dot{i},t,Rd} \quad \text{à } t = 0 \quad (\text{avec } k_{y,\theta} = 1)$$

$$\mu_0 = \frac{315,9}{935,7} = 0,338$$

$$\theta_{a,cr} = 39,19 \cdot \ln \left(\frac{1}{0,9674 \cdot \mu_0^{3,833}} - 1 \right) + 482 = 646^{\circ}\text{C}$$

Benefit of High strength steels – R30 steel structure without any additional passive fire protection

Calculation of the resistance time under ISO fire



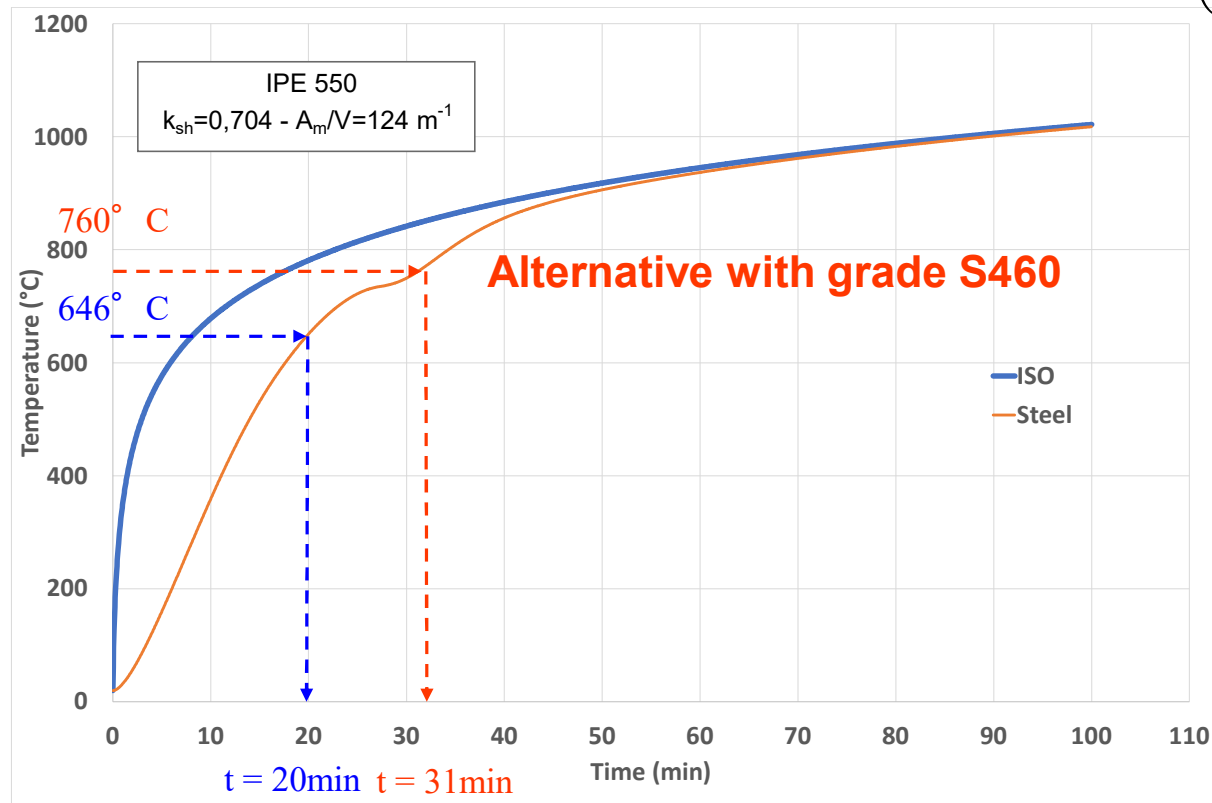
$$\Delta\theta_{a,t} = k_{sh} \cdot \frac{A_m / V}{c_a \cdot \rho_a} \cdot \dot{h}_{net} \cdot \Delta t$$

$$k_{sh} = 0,9 \frac{[Am / V]_b}{[Am / V]} = 0,704$$

Benefit of High strength steels – R30 steel structure without any additional passive fire protection

Calculation of the resistance time under ISO fire

$$\theta_{a,cr} = 39,19 \cdot \ln \left(\frac{1}{0,9674 \cdot \mu_0^{3,833}} - 1 \right) + 482$$



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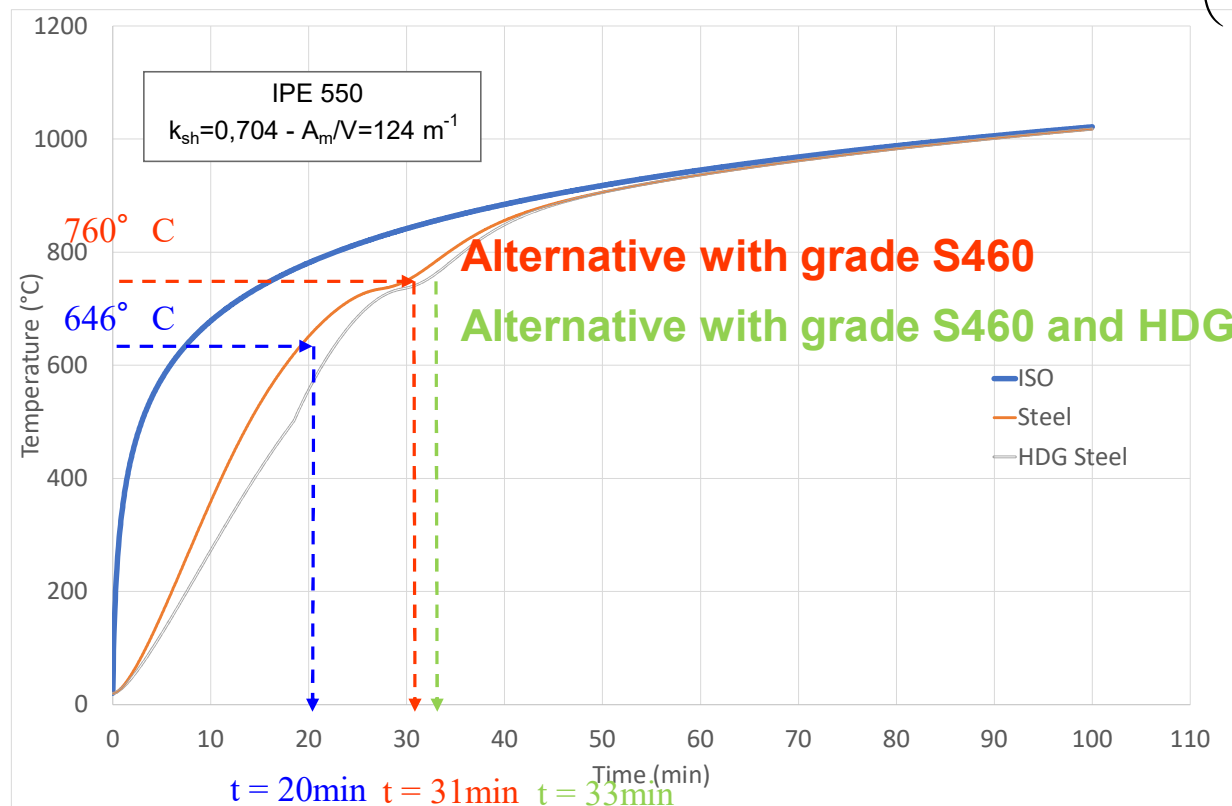
$$k_{sh} = 0,9 \frac{[A_m / V]_b}{[A_m / V]} = 0,704$$

R30 fire protection:
Extra cost for S460/S500 steel
: 5 times lower than cost of an
R30 intumescent paint.

Benefit of High strength steels – R30 steel structure without any additional passive fire protection

Calculation of the resistance time under ISO fire

$$\theta_{a,cr} = 39,19 \cdot \ln \left(\frac{1}{0,9674 \cdot \mu_0^{3,833}} - 1 \right) + 482$$



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$$k_{sh} = 0,9 \frac{[A_m/V]_b}{[A_m/V]} = 0,704$$

R30 fire protection:
Extra cost for S460/S500 steel
: 5 times lower than cost of an
R30 intumescent paint.

Beams with large web openings

Thermal response

Annex E (normative)

Beams with large web openings

E.1 General

(1) This Annex is applicable to steel beams with large web openings within the scope of EN 1993-1-13.

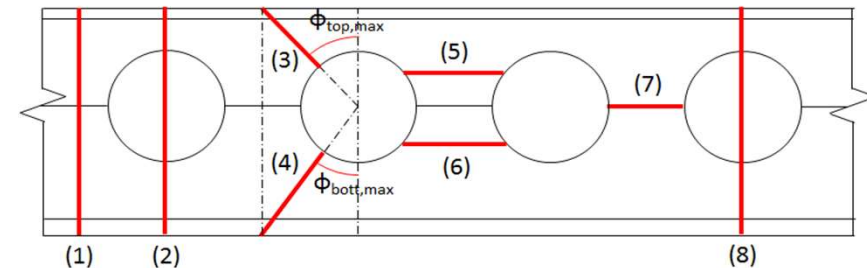
E.2 Thermal response

(1) Evolution of temperature may be calculated from Formula (7.51), using section factors which depend on whether a uniform or non-uniform temperature approach is adopted.

(2) For a uniform temperature approach, section factors should be calculated for the different failure modes, as follows:

- Flexural bending in a gross section (no opening): from case (1) in Table E.1
- Flexural bending in a net section (with an opening) from case (2) in Table E.1
- *Vierendeel* bending from case (3) in Table E.1 for the top chord or (4) for the bottom chord
- Web post buckling: from case (5) in Table E.1 for the top chord or (6) for the bottom chord
- Web horizontal shear or weld shear at the junction of the chords: from case (7) in Table E.1
- Web vertical shear: from case (8) in Table E.1.

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



Beams with large web openings

Mechanical response

According EN 1993-1-13

With additional rules of EN 1993-1-2 for

- Classification of cross sections :
 - 0.85 multiplies ε
 - Specific rules for beams with sinusoidal openings
- Resistance/stability formulae at the opening: replacing f_y by $f_{y,\theta}$, E_a by $E_{a,\theta}$ and γ_{M0} , γ_{M1} , γ_{M2} by $\gamma_{M,fi}$
- Web buckling near widely spaced opening and web post buckling: buckling under fire conditions χ_{fi}

Beams with large web openings

Mechanical response

Fully covered by new Standards

Fire design of unprotected cellular steel beam : according to EN 1993-1-2 and EN 1993-1-13

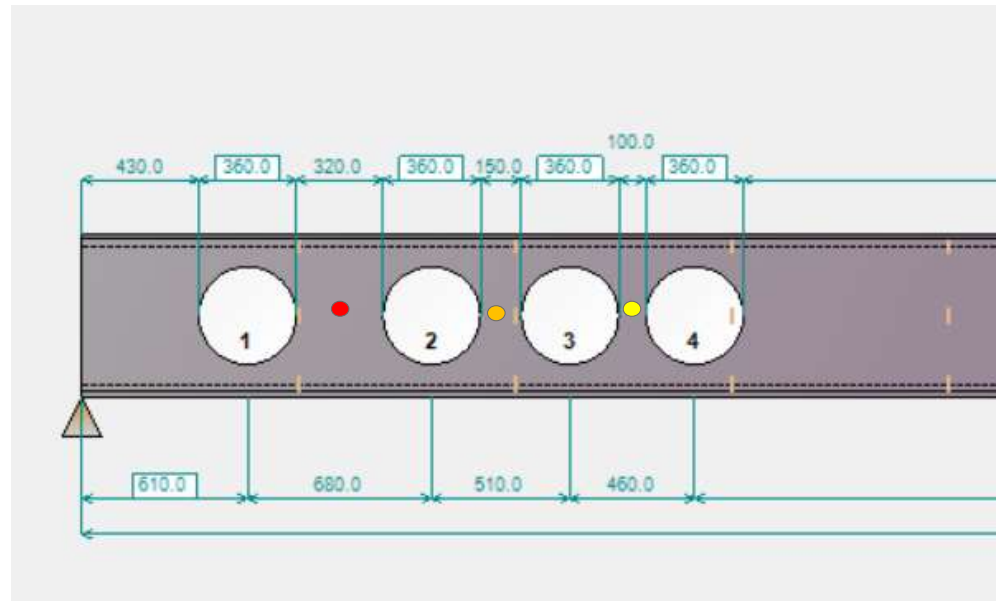
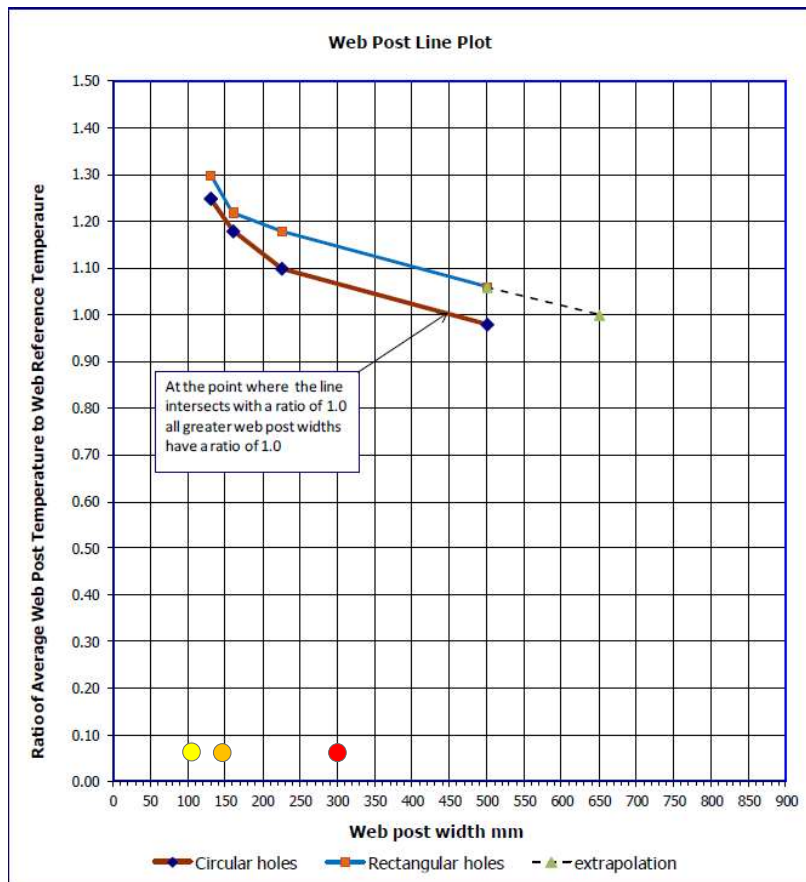
Fire design of protected cellular steel beam : according to EN 1993-1-2 and EN 1993-1-13 and

- EN 13381-4 for non reactive protection
 - For protected beams with regular openings, the thickness of fire protection is determined according to EN 13381-4 based on the section factor defined and on the critical temperatures obtained for the different failure modes.
- EN 13381-8 and -9 for reactive protection
 - Additionally, the critical temperature of beams protected by reactive coatings should be decreased for failure modes corresponding to the web resistance or stability, according to EN 13381-9.
 - Note: EN 13381-9 provides a web modification factor which is product specific and function of the web-post length. It considers the difference in the rate of heating between a web post and a solid web section.

Beams with large web openings

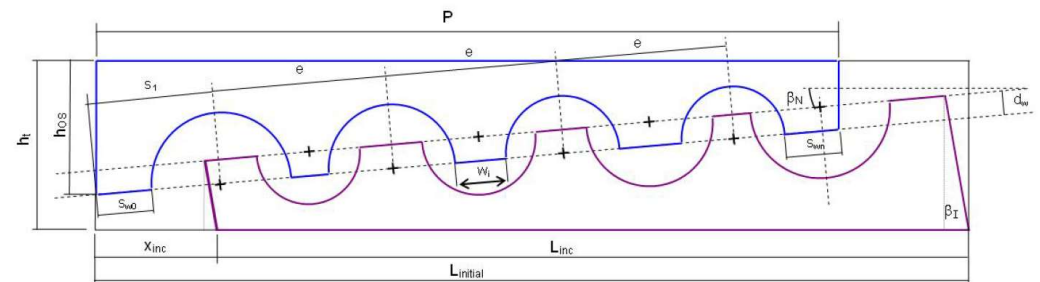
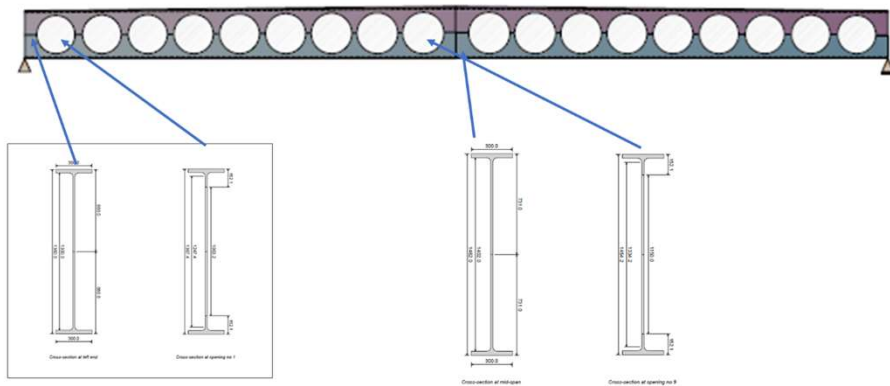
Protection with intumescent paint – EN 13381-9

Web modification factor which is product specific and function of the web-post length.



Beams with large web openings - Protection with intumescent paint – EN 13381-9

Cellular beams: Example: 24 span tapered cellular beam with R30 fire requirement



- HEA 900: $A_m/V = 92 \text{ m}^{-1} \rightarrow$ Intumescent paint layer 472μ according to EN 13381-8
- Tapered beam based on a HEA 900: $A_m/V = 125 \text{ m}^{-1} \rightarrow$ Intumescent paint layer 486μ

Composite Steel/Concrete structures: Eurocode 4 fire part : EN 1994-1-2

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What about the scope ?

Concrete-filled tubular sections

Scope of current EN 1994-1-2 limited due to unsafe predictions of buckling resistance of CFTS

New Annex F will cover Circular, Square, Elliptical and Rectangular Hollow Sections

- Concrete core:

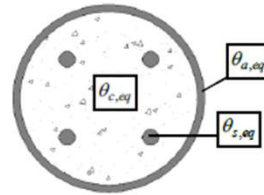
$$\theta_{c,eq} = 81.8 - 5.05t_f + 0.003t_f^2 - 15.07A_m/V + 0.3(A_m/V)^2 - 0.88t_f \cdot A_m/V + 7.43t_f^{0.842}(A_m/V)^{0.714}$$

- Steel tube:

$$\theta_{s,eq} = -824.67 - 5.58t_f + 0.007t_f^2 - 0.01t_f \cdot A_m/V + 645.08t_f^{0.289}(A_m/V)^{0.017}$$

- Reinforcing bars:

$$\theta_{s,eq} = \beta_3(t_f/u_s^2)^3 + \beta_2(t_f/u_s^2)^2 + \beta_1(t_f/u_s^2) + \beta_0$$

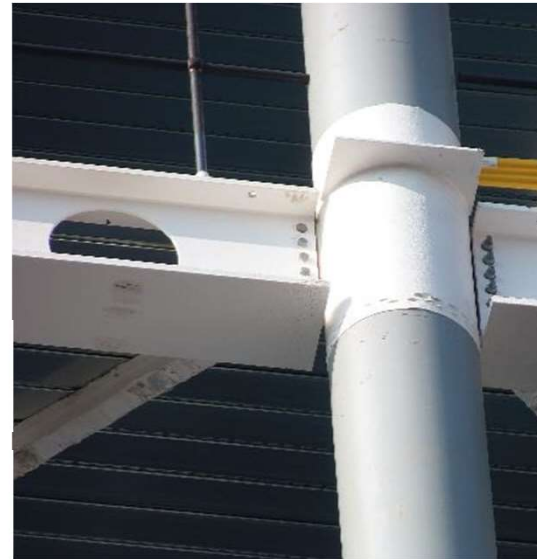


(3) The design value of the plastic resistance to axial compression in the fire situation is given by:

$$N_{fi,pl,Rd} = A_a f_{y,\theta}(\theta_{a,eq}) / \gamma_{M,fi,a} + A_c f_{c,\theta}(\theta_{c,eq}) / \gamma_{M,fi,c} + A_s f_{s,\theta}(\theta_{s,eq}) / \gamma_{M,fi,s}$$

(4) The effective flexural stiffness is calculated as:

$$(EI)_{fi,eff} = \varphi_{a,\theta} E_{a,\theta}(\theta_{a,eq}) I_a + \varphi_{c,\theta} E_{c,\theta}(\theta_{c,eq}) I_c + \varphi_{s,\theta} E_{s,\theta}(\theta_{s,eq}) I_s$$



Eurocode 4 fire part : EN 1994-1-2 : Composite Shallow floor

Composite Steel/Concrete structures: Eurocode 4 fire part : EN 1994-1-2
Main relevant improvements: **composite Slim Floor**

- 7.4 Composite beam
- 7.4.2.4 Composite shallow floor beams
- 8.3 Mechanical analysis
- 8.4 Validation of advanced design methods



- Section 9 Detailing
- 9.1 General
- 9.2 Composite beams
- 9.2.1 Composite beams comprising steel beams with partial encasement
- 9.2.2 Composite shallow floor beams

Annex H [Normative] Calculation of the sagging moment resistance $M_{fi,Rd+}$ of shallow floor beams

- H.1 Introduction
- H.2 Calculation of the sagging moment resistance $M_{fi,Rd+}$

Composite Steel/Concrete structures: Eurocode 4 fire part : EN 1994-1-2

Composite Shallow Floor

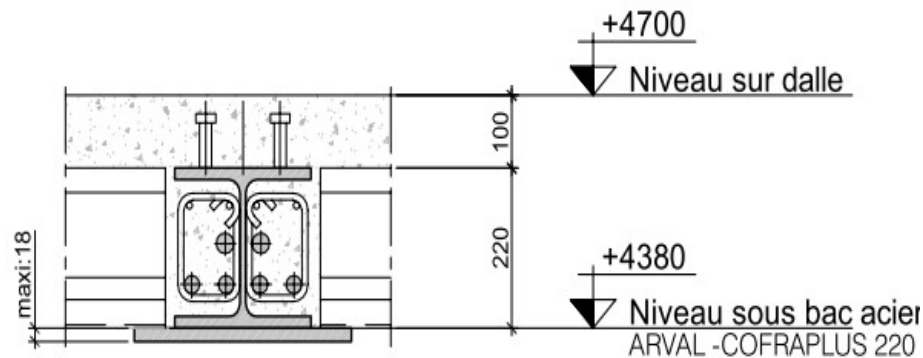
Example: Galerie Konz



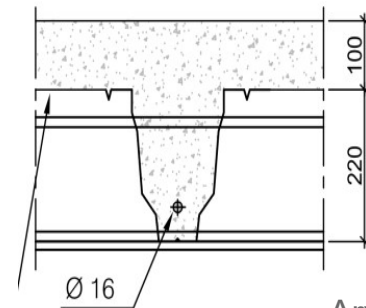
Copyright : F. Benyahia (Schroeder Associés)

Case study «Galerie KONS»

- Beam span : 9.45 m
- Section HEB 220 (S460) + plate 350*25 mm (S355)
- Slab span: 5.40 m
- Fire resistance REI 90 achieved with additional longitudinal rebars : 2 Φ 25+ 1 Φ 28 S500 per side



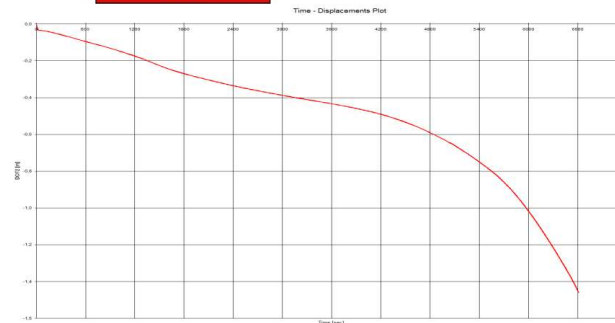
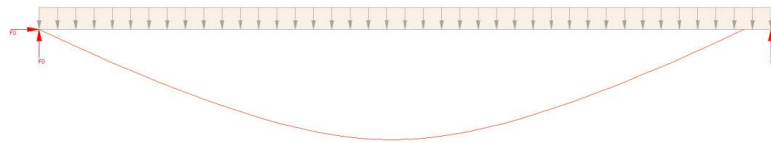
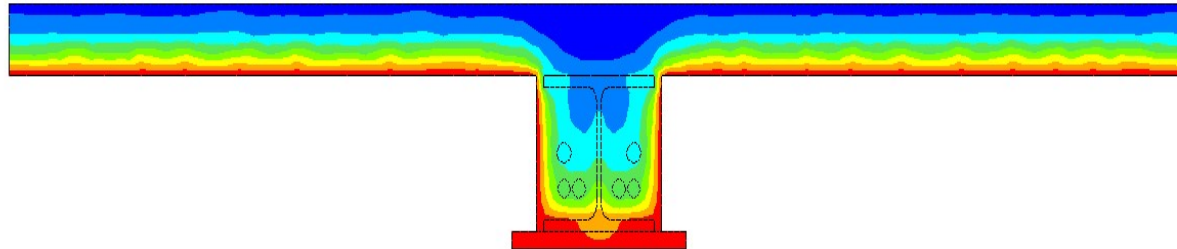
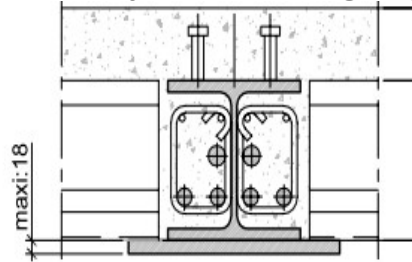
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Arval COFRAPLUS 220

Case study «Galerie KONS» (Luxembourg)

- Fire Design made in 2015
- Different methods published at that time but no one fully recognised by Eurocode or national regulations
- Advanced calculation method requested by check office
- Today, such a design/approval would be much quicker and easier thanks to Annex H of EN 1994-1-2



Diamond 2011.a.2 for SAFIR

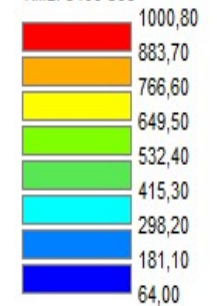
FILE: HE220B%25_2D28

NODES: 966

ELEMENTS: 1588

CONTOUR PLOT
TEMPERATURE PLOT

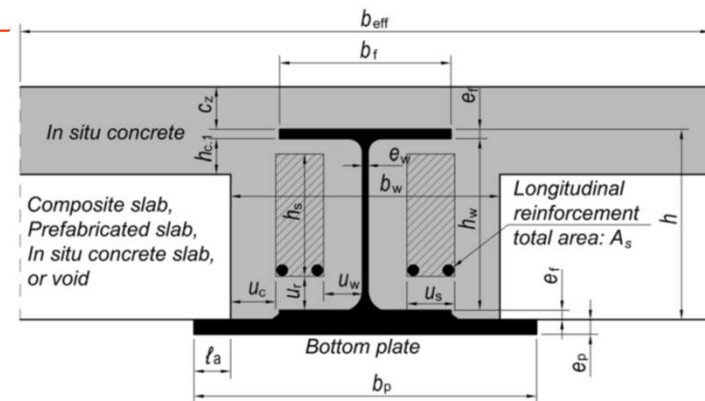
TIME: 5400 sec



Eurocode 4 fire part : EN 1994-1-2 : Composite Shallow floor

Use of new Annex H of EN 1994-1-2 leads to the following conclusions in case of a composite shallow floor designed according to EN 1994-1-1:

- R30 : Fire resistance automatically achieved
- R60 : Fire resistance almost always achieved; some additional longitudinal rebars might be needed.
- R90/R120 : Additional longitudinal **rebars needed, which can be optimised through Annex H of EN 1994-1-2**



(14) For reinforcement located within the zone determined by h_s and u_s according to Figure J.1, the Temperature of this longitudinal reinforcement θ_r can be calculated using equation (J.8):

$$\theta_r = A_r \cdot u_{eq}^2 + B_r \cdot u_{eq} + C_r \quad (J.8)$$

where:

u_{eq} is the equivalent distance and can be calculated with: $u_{eq} = \min \left[45\text{mm}, 25\text{mm} + \frac{e_p + e_f}{2} \right] +$

$$\frac{5\text{mm}}{k_c}$$

A_r , B_r , C_r are given in Table J.3.

Table J.3: Parameters for determination of the bending resistance

Parameter	R30	R60	R90	R120
A_f	0	0.0954	0.0548	0.0381
B_f	0	-19.254	-15.130	-12.797
C_f	300	1105.4	1135.9	1138.1

Composite Steel/Concrete structures: Eurocode 4 fire part : EN 1994-1-2

Membrane Action

4.8 Analysis of parts of the structure



(5) A composite floor constructed of primary steel/composite beams, secondary steel/composite beams and composite slabs can be divided into a number of structural zones, each of which being analysed separately. The fire resistance of each zone can be justified by considering the tensile membrane effect that can develop in the composite floor slab supported by the surrounding edge beams, thereby allowing elimination of fire protection to the internal secondary beams.

(6) This tensile membrane effect shall be justified by advanced design methods described in Section 8 considering material and geometrical non-linearities or by using accepted simplified design methods.

NOTE: Annex G provides a simplified design method.

(7) The edge beams should be able to resist the additional vertical loads from the load distribution path of tensile membrane action.

Composite Steel/Concrete structures: Eurocode 4 fire part : EN 1994-1-2

Membrane Action

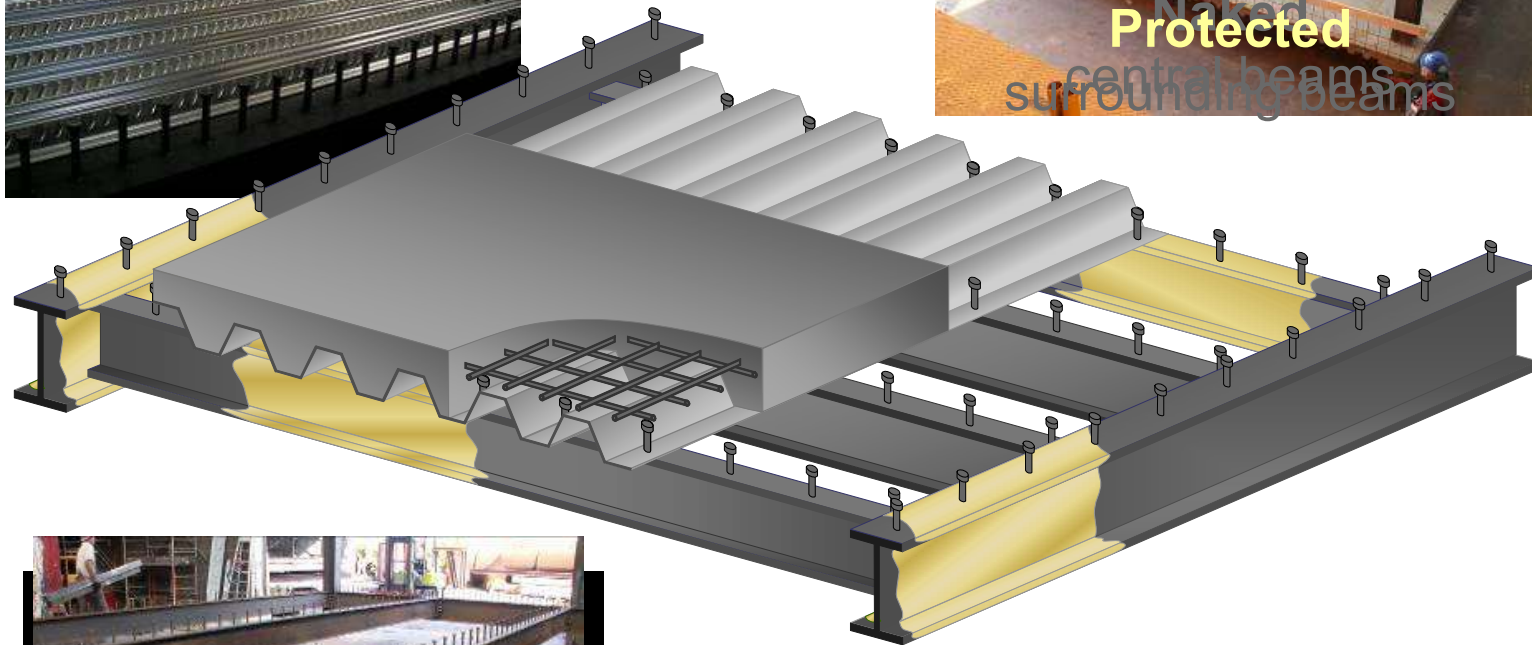
Annex G [Informative]

Simple calculation model of fire resistance of steel and concrete composite floors under tensile membrane action

- 
- G.1 Introduction
 - G.2. Field of application
 - G.3. Floor design zones
 - G.4 Temperature distribution
 - G.5 Calculation of floor loadbearing capacity under tensile membrane action.
 - G.5.1 Calculation of slab loadbearing capacity
 - G.5.2 Calculation of loadbearing capacity of unprotected secondary beams inside the floor design zone
 - G.5.3 Calculation of the total loadbearing capacity of the floor design zone
 - G.5.4 Loading condition of beams on the perimeter of the floor design zone
 - G.6 Detailing

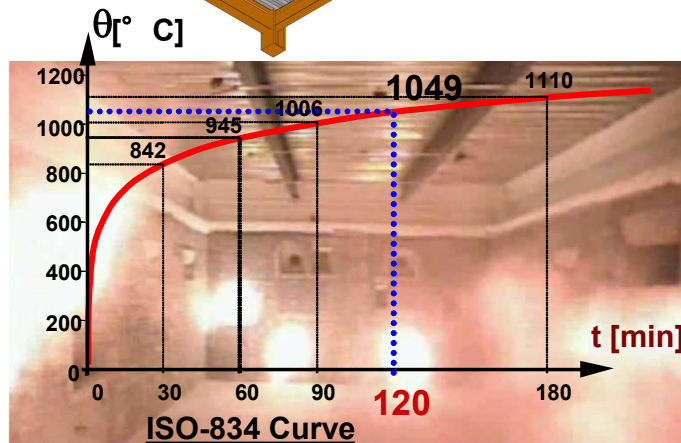
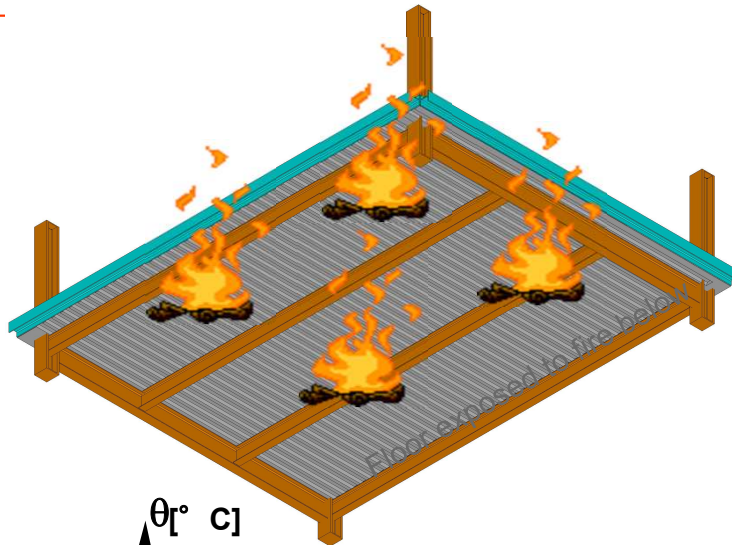
Composite Steel/Concrete structures: Eurocode 4 fire part : EN 1994-1-2

Membrane Action – Fire test FRACOF



Composite Steel/Concrete structures: Eurocode 4 fire part : EN 1994-1-2

Membrane Action – Fracof Fire test



Loading condition

Uniform loading through 15 sand bags to simulate

➤ Dead load: $1,25 \text{ kN/m}^2$

➤ Imposed load: $5,0 \text{ kN/m}^2$



Weight of each sand bag = **1500 kg**

Equivalent uniform load
 $3,87 \text{ kN/m}^2 \approx (1,25 + 0,5 \times 5)$

Partitions

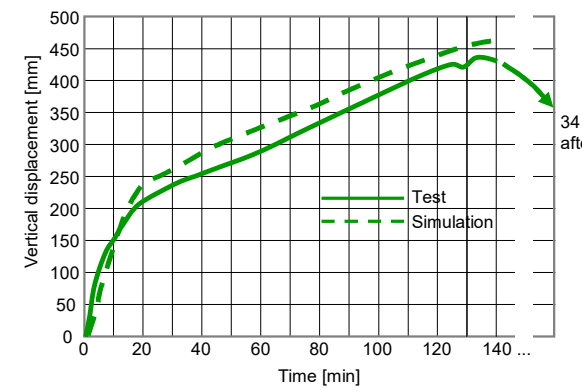
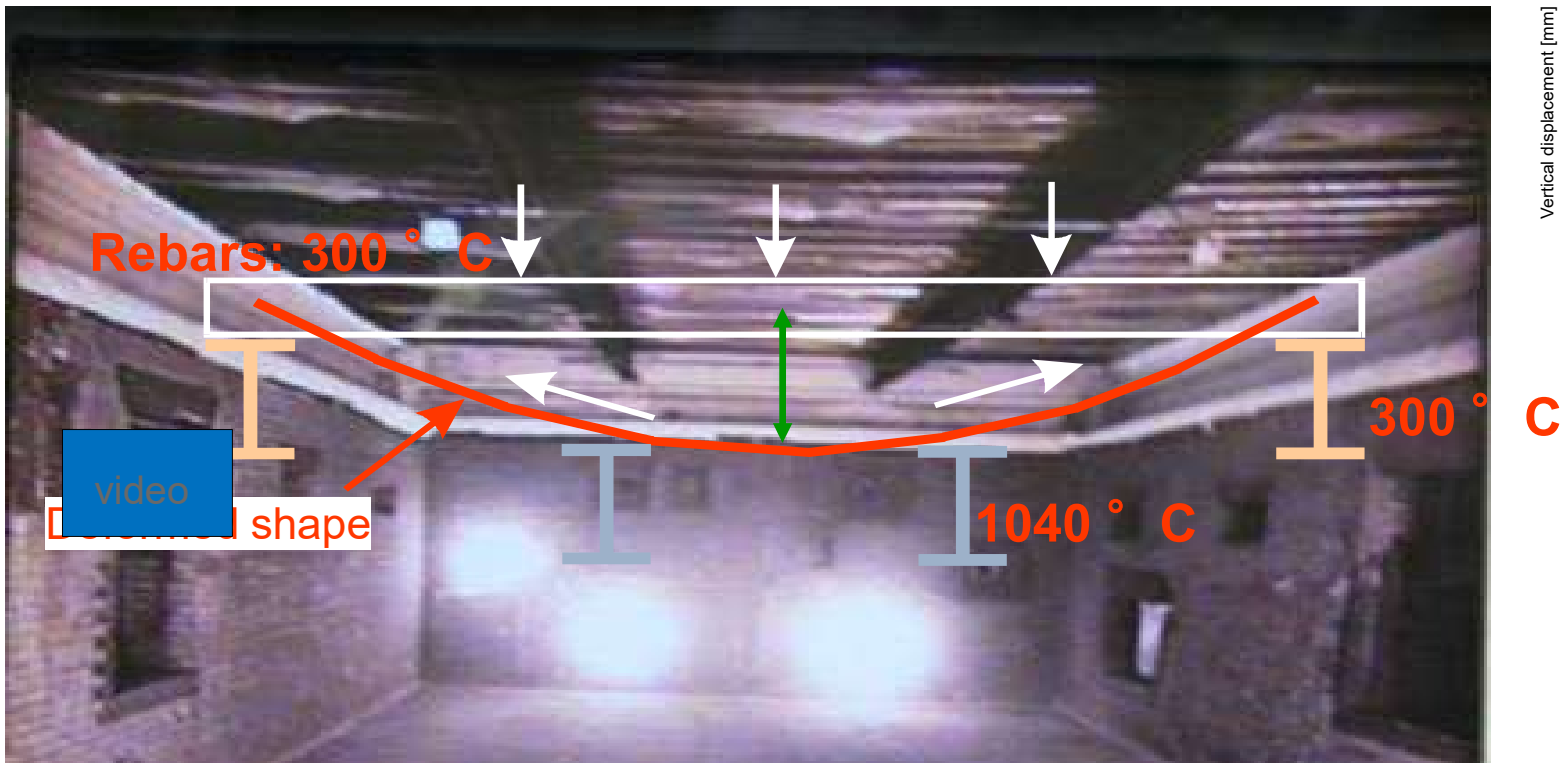
ψ_1

Imposed
Loads

Composite Steel/Concrete structures: Eurocode 4 fire part : EN 1994-1-2

Membrane Action – Fracof Fire test

Test results
R > 120 minutes



Composite Steel/Concrete structures: Eurocode 4 fire part : EN 1994-1-2

Membrane Action - **ACB Fire test in Ulster**



video

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Composite Steel/Concrete structures: Eurocode 4 fire part : EN 1994-1-2

Membrane Action - **ACB Fire test in Ulster**



**Reference
Buildings**



**School in
Turkey**



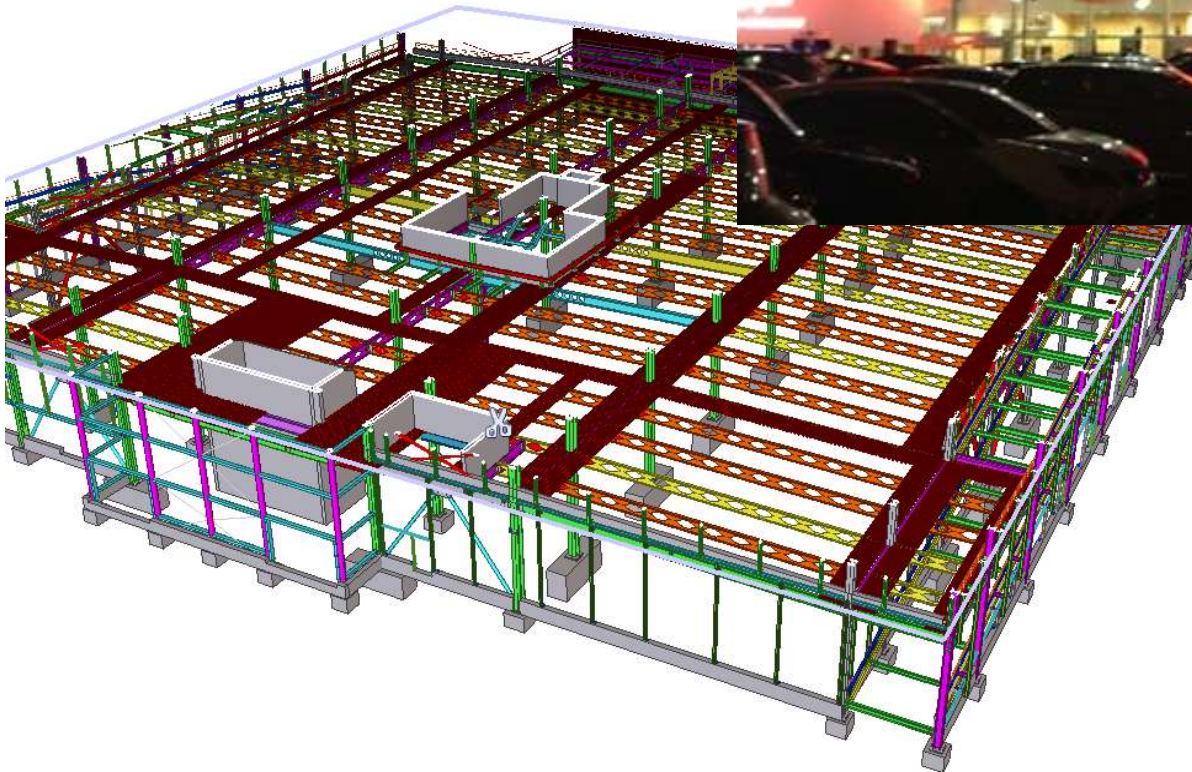
**Protected
Primary beams**

**Unprotected
Secondary
beams**

Composite Steel/Concrete structures: Eurocode 4 fire part : EN 1994-1-2

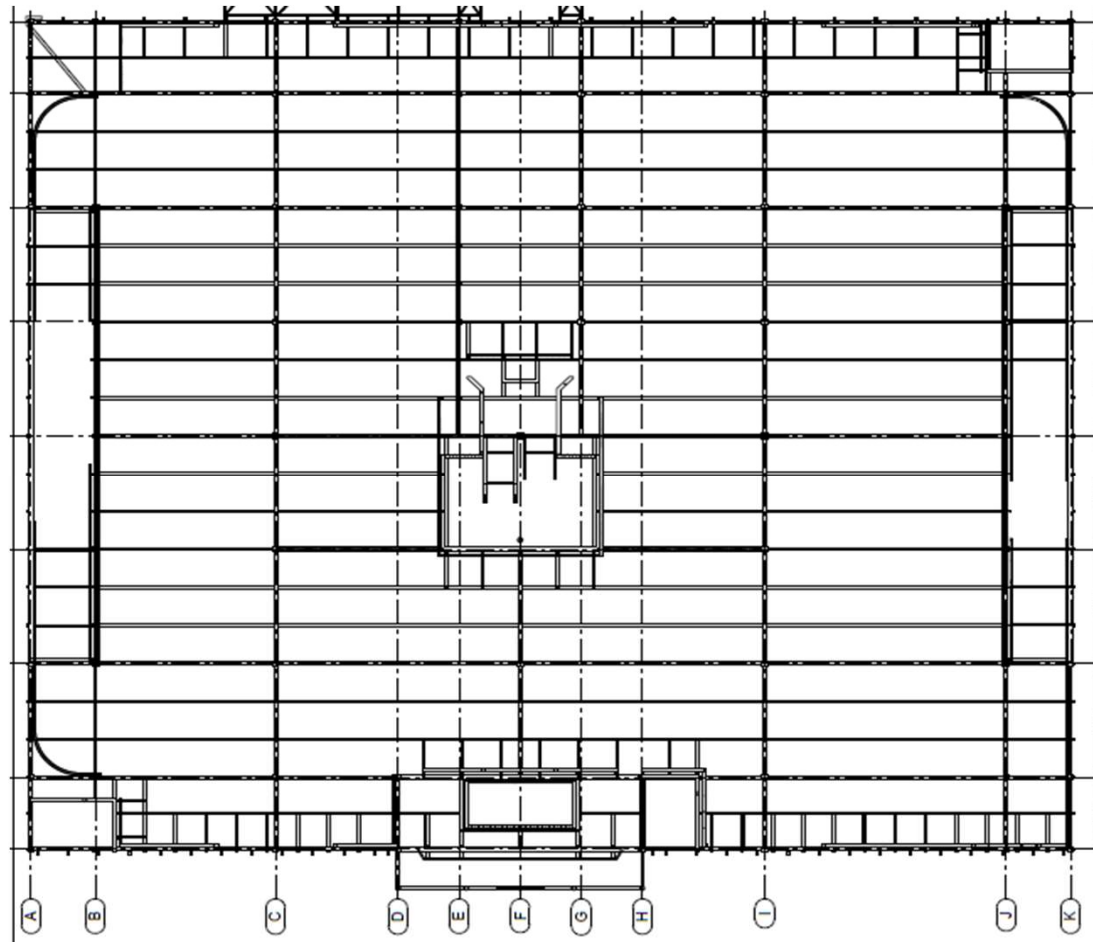
Membrane Action

Example



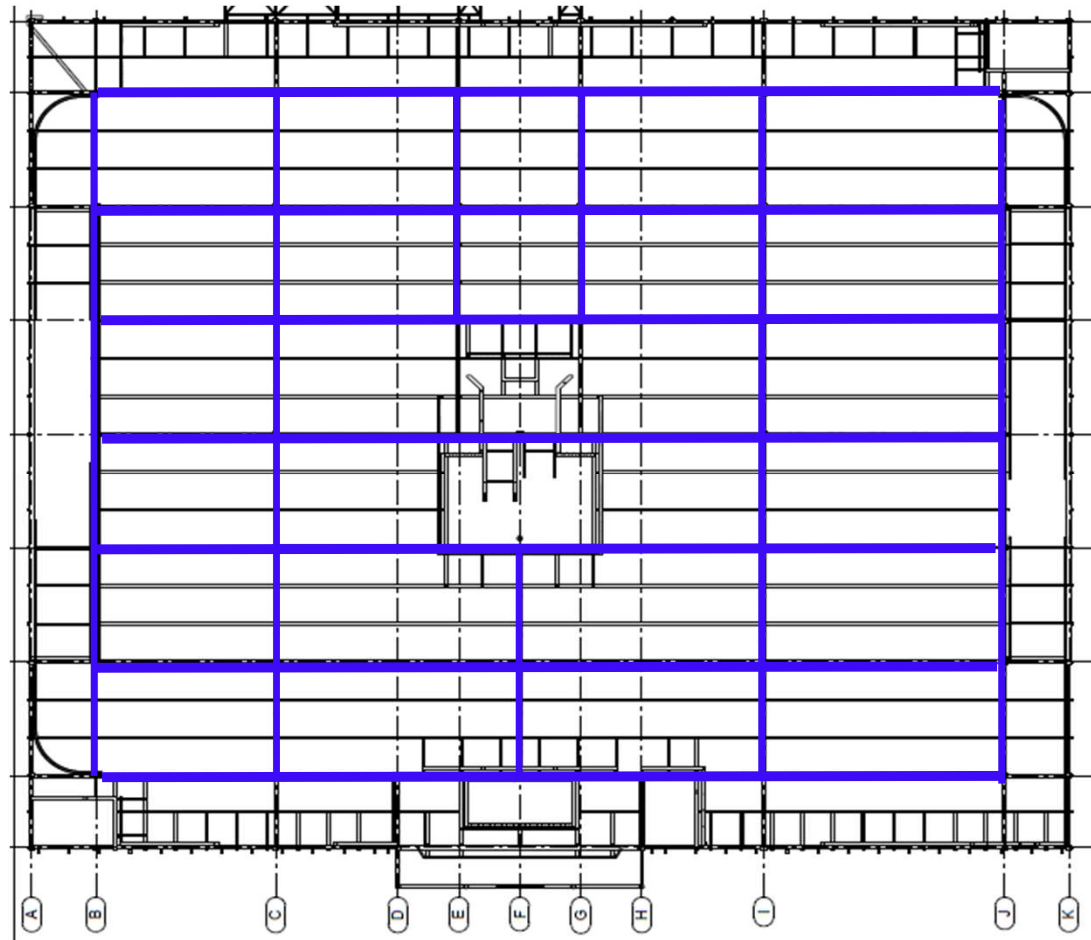
Composite Steel/Concrete structures: Eurocode 4 fire part : EN 1994-1-2

Membrane Action – Example Building GERIC near Thionville



Composite Steel/Concrete structures: Eurocode 4 fire part : EN 1994-1-2

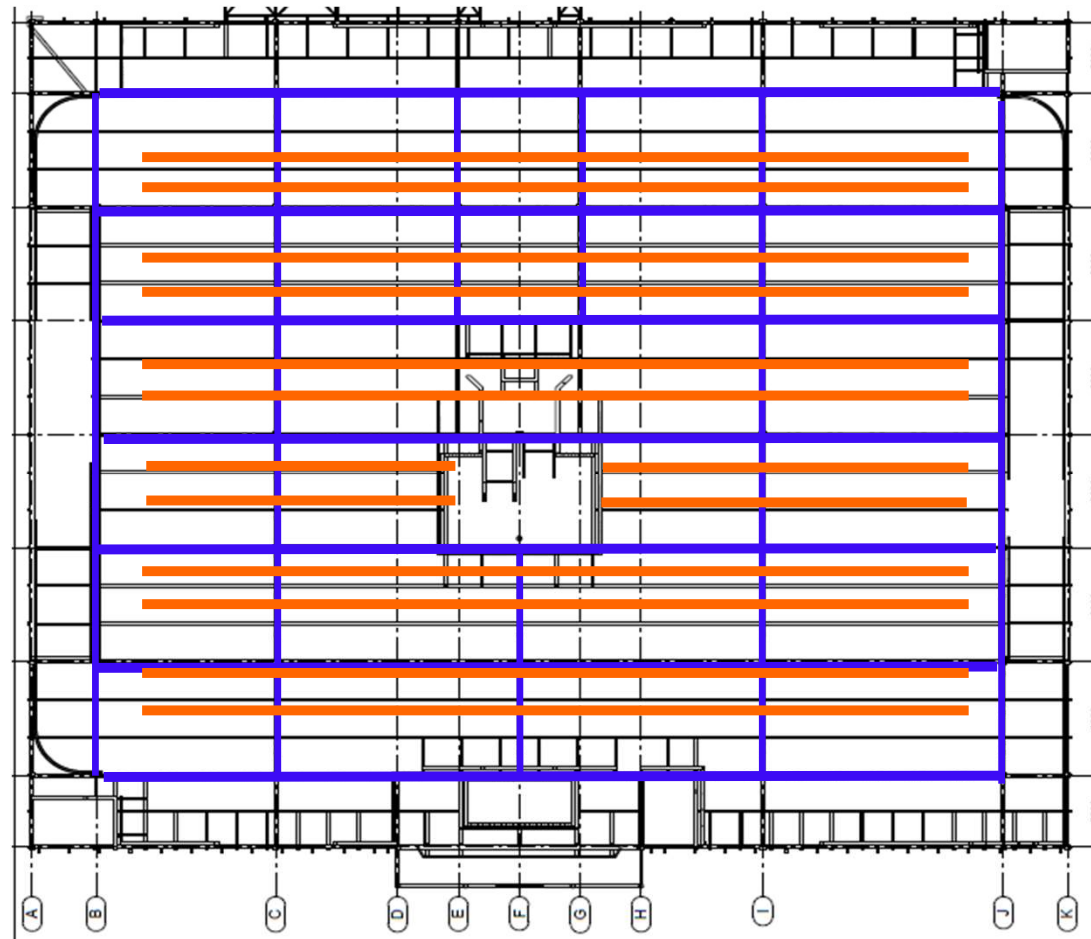
Membrane Action – Example Building GERIC near Thionville



Protected
Beams

Composite Steel/Concrete structures: Eurocode 4 fire part : EN 1994-1-2

Membrane Action – Example Building GERIC near Thionville (F)



Protected
Beams

Unprotected
Beams

Composite Steel/Concrete structures: Eurocode 4 fire part : EN 1994-1-2 – Beams with large web openings

(12) Evolution of temperature of a beam with large web openings should be calculated according to Annex E of EN 1993-1-2, using section factors which depend on whether a uniform or non-uniform temperature approach is adopted.



7.4.2.1 General

(1)P Composite beams shall be checked for:
resistance of critical cross-sections, see (6) to (8);
vertical shear, see (9) to (11);
resistance to longitudinal shear, see (12) to (17).

NOTE Guidance on critical cross-sections is given in 6.1.1(4)P of EN1994-1-1.

Composite Steel/Concrete structures: Eurocode 4 fire part : EN 1994-1-2 – Beams with large web openings

(2)P In addition to (1), composite beams with large web openings shall be checked for:
resistance to *Vierendeel* bending, see (18) and (19).
web buckling resistance in case of widely spaced openings, see (18) and (19).
web-post buckling, shear and bending resistance in case of closely spaced openings, see (18) and (19).

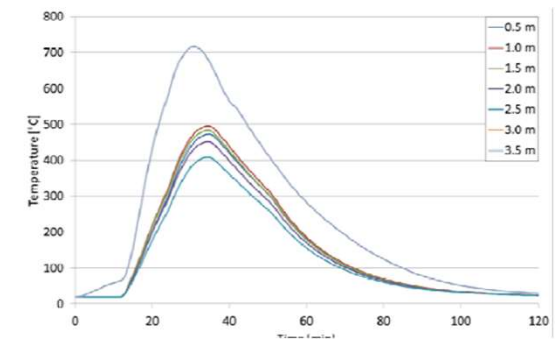
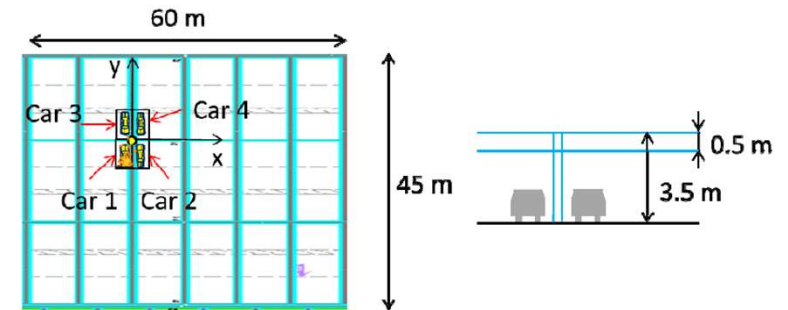
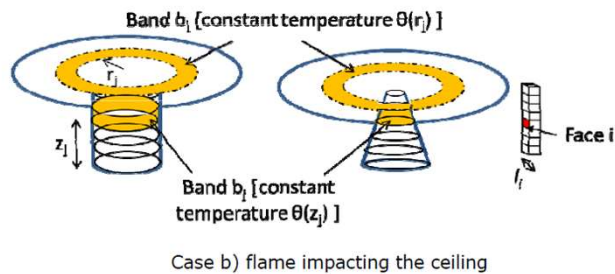
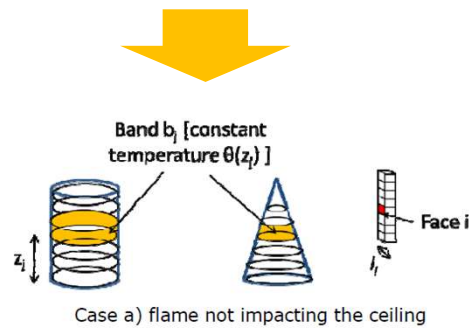
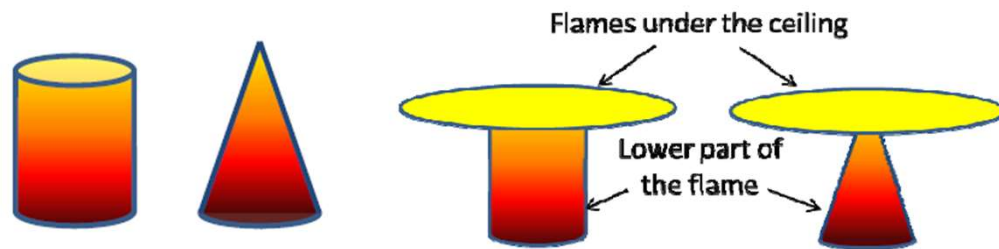


The verification of composite beams with large web openings in zones with no openings should be done according to rules for composite beams without web openings, see (1).

(19) The resistance of the steel elements at the opening at a particular temperature θ is obtained by application of EN 1993-1-13 and EN 1994-1-1, replacing f_y by $f_y(\theta)$, E by $E(\theta)$ and γ_{M0} , γ_{M1} , γ_{M2} by $\gamma_{M,fi}$ according to Table 5.3.

(20) Additional rules for beams with large web openings in case of stiff slabs (definition according to Annex D of EN 1994-1-1)

Actions on structures: Eurocode 1 fire part : EN 1991-1-2 – Localized fires





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Thanks for listening

Dr. Ir. François HANUS

Steligence® Fabrication Center

ILNAS Representative

+352661073172 | Francois.Hanus@arcelormittal.com