EPFL

RESSLab

Fire Safety & Engineering SA

Fire Protection Engineering

Introductory Course – Part 1

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Fire protection expert with federal diploma

Personal background

- 1998 Degree in civil engineering HES in Yverdon-les-Bains
- 2011 CAS in Building Fire Protection
- 2016 Federal Diploma of Fire Protection Expert

1998 - 2015	Daniel Willi SA Civil Engineering Office
2016 - 2017	Expert in fire prevention and engineering at ECA-Vaud
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Member of the European network of experts *Secure with Steel*

Professional Member of the *Society of Fire Protection Engineering*

Member of the Technical Commission

Summary

- What is fire? How does it develop?
- What is the risk of fire in Switzerland around the world?
- Structural Impacts
- Designing a safe building in the event of a fire
- Fire protection requirements
- Design in a "fire" situation

What is fire?

How does it develop?

What are these effects?

All the laws that govern our universe are manifested in the phenomena that a simple candle will give us the opportunity to review.

Michel Faraday (1791 – 1867)

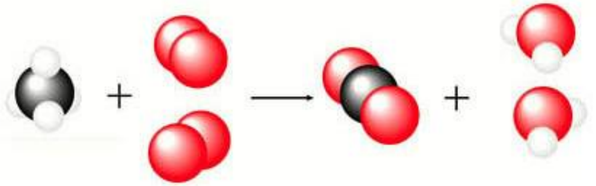
What is fire?

- An uncontrolled chemical reaction producing light and enough energy to cause burns.
- It is also referred to as combustion, which is a chemical reaction between fuel and the oxygen contained in the air.
- The power of a fire is expressed in Kilowatts.
- **Main causes of fires**
- Natural
  - Lightning
  - Storms (power line break)
  - Earthquakes (burst pipes)
- Human
  - Open flames
  - Explosive environment
  - Inattention
  - Chemical reactions

What is fire?

Chemical phenomenon (exothermic redox reaction)

Fuel + Oxygen → Product of Combustion



Example 1 : $CH_4 + 2\ O_2 \rightarrow CO_2 + H_2O$ + heat

<u>Ideal combustion (methane) = no harmful residues</u>

Example 2 : BOIS + $O_2 \rightarrow CO_2 + H_2O$ + CO + Residues + heat

<u>Real combustion WITH harmful residues</u>

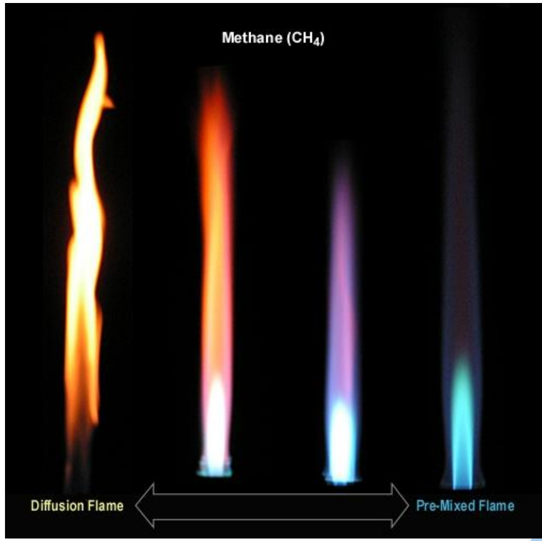
Types of fires

Diffusion flame : A combustion process where gaseous fuel and oxygen are transported in a reaction due to a difference in concentration (Fick's law).

- Moves from highest to lowest concentration.
- Natural flames are diffusion flames
  - Matches
  - Candle

Pre-mixed flame : A mixture of gaseous fuel and oxygen prior to ignition and propagation.

- Controlled combustion
  - Acetylene torch
  - Aircraft engine
- Uncontrolled combustion
  - Methane leak
  - Fire in a confined space



Types of fires

Smoldering Fire
- Very slow burning.
- Carbonization with temperatures between 300 and 1000 °C.
- Solids occur on the surface.
- Produces lethal levels of carbon monoxide (CO).
  - Cigar
  - Upholstered chair
  - Charcoal grill

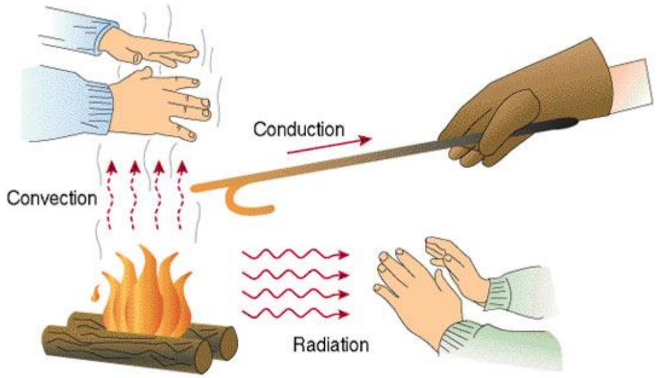
Spontaneous combustion
- Starts with a slow oxidation of a fuel exposed to air.
- Very little heat loss.
- Thermal runaway.
  - Hay bales (thermal reaction due to putrefaction)
  - Sawdust silo

Heat transfers

- Combustion releases heat, which can ignite other fuels in the vicinity of the fire.
- These transfers are governed by the first and second laws of thermodynamics.
  - 1st principle: during any transformation, there is conservation of energy.
  - 2nd principle: irreversibility of physical phenomena, in particular during thermal exchanges.

- Thermal energy always moves from hottest to coldest.

- There are three possible methods of transferring heat:
  - Conduction
  - Convection
  - Radiation

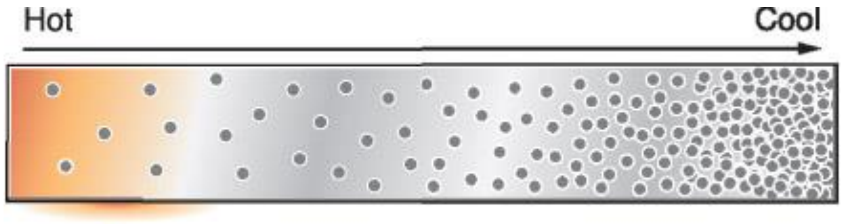


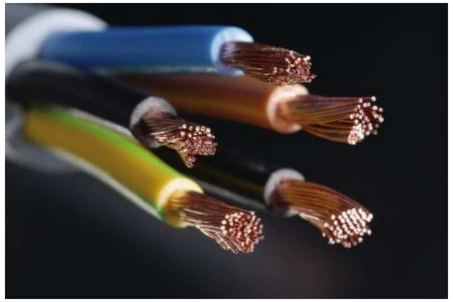
Conduction

Heat transfer caused by a difference in temperature between two regions of the same medium, and occurring without overall displacement of matter (on a macroscopic scale).

- Conductive materials transfer heat well
  - Copper
  - Steel

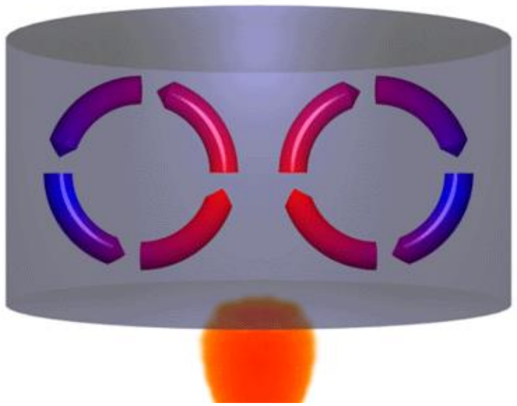
- Insulation materials do not transfer heat well.
  - Glass or rock wool
  - Polystyrene
  - Air





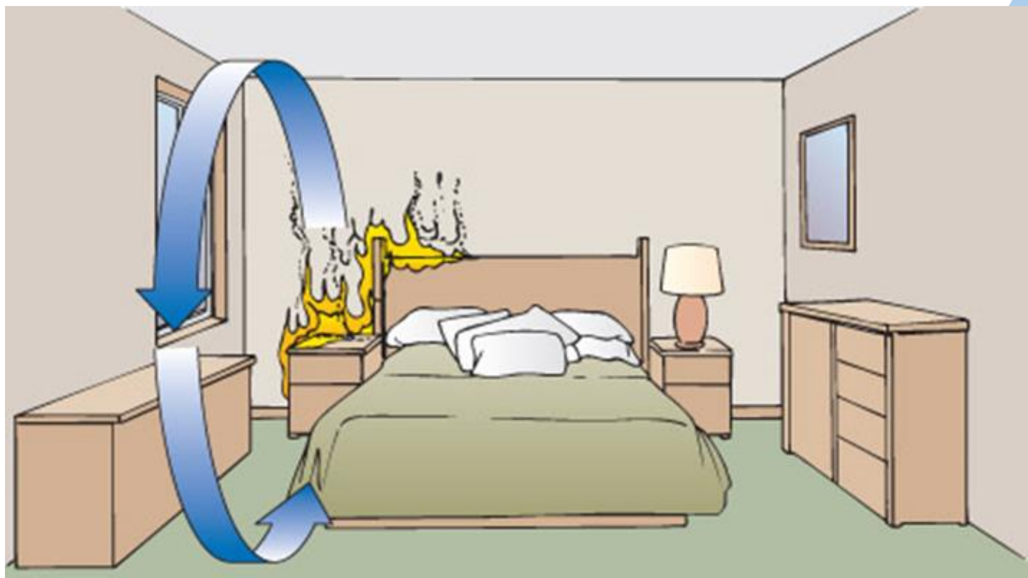
Convection

Convection refers to the set of internal movements that animate a fluid and that involve the transport of the properties of the parcels of this fluid during its movement. This transfer involves the exchange of heat between a surface and a moving fluid in contact with it, or the displacement of heat within a fluid by the overall movement of its molecules from one point to another.



Convection in a room on fire

- The hot gases rise and then move horizontally.
- When they encounter cold walls, they come back down.
- Where they leave the room through openings (doors, windows).



Radiation

Radiation, synonymous with radiation, refers to the process of emission or propagation of energy and momentum involving a wave. In the case of fire, it is electromagnetic radiation.
It does not need a support to spread (sunlight).

Thermal radiation can ignite building components or cause burns.

Example of a flow

▪ Cloudless sun	~ 1.0 kW/m^2
▪ Pain on bare skin	~ 2.0 kW/m^2
▪ Burning on bare skin	~ 4.0 kW/m^2
▪ Ignition of objects	~ 10 - 20 kW/m^2

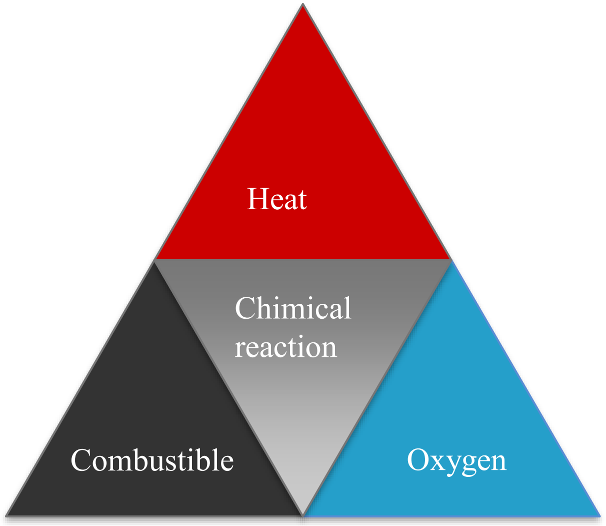
Fire Basis and Development

Why does it burn?

There are three things that are needed for combustion to occur:

- Fuel
- Oxygen (21% in air)
- Heat

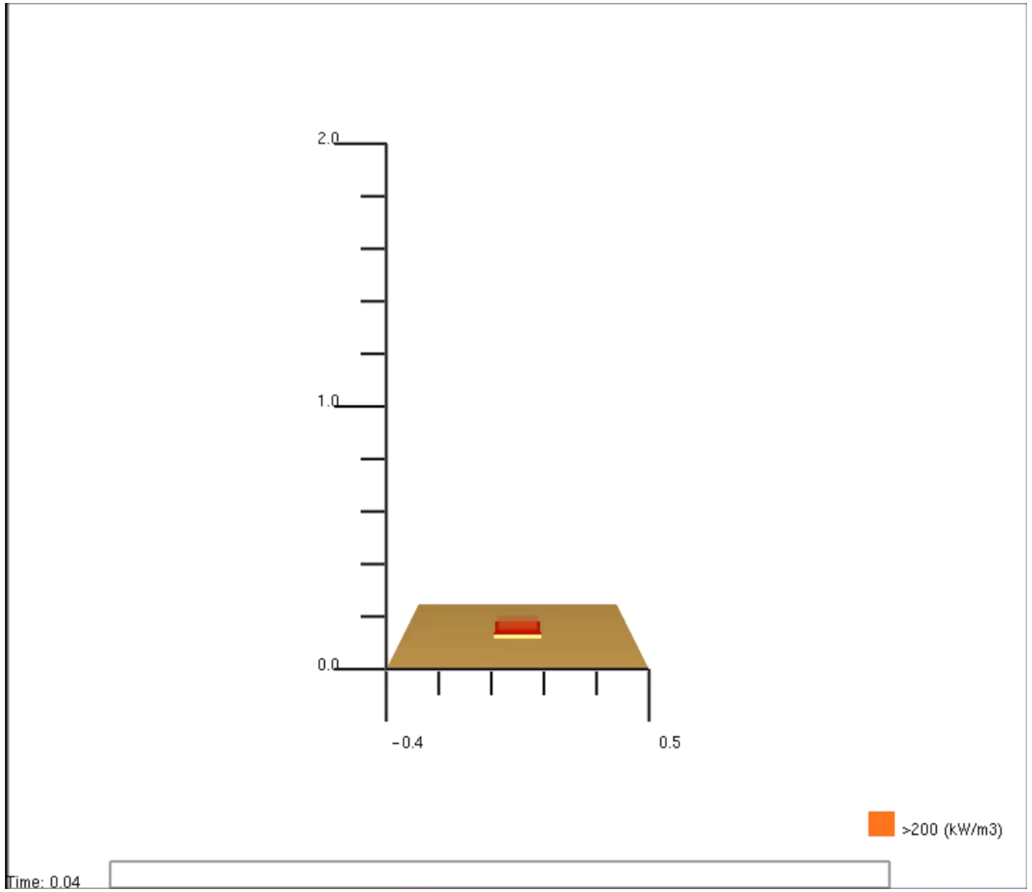
Chemical chain reactions (free radicals) keep fire developing.

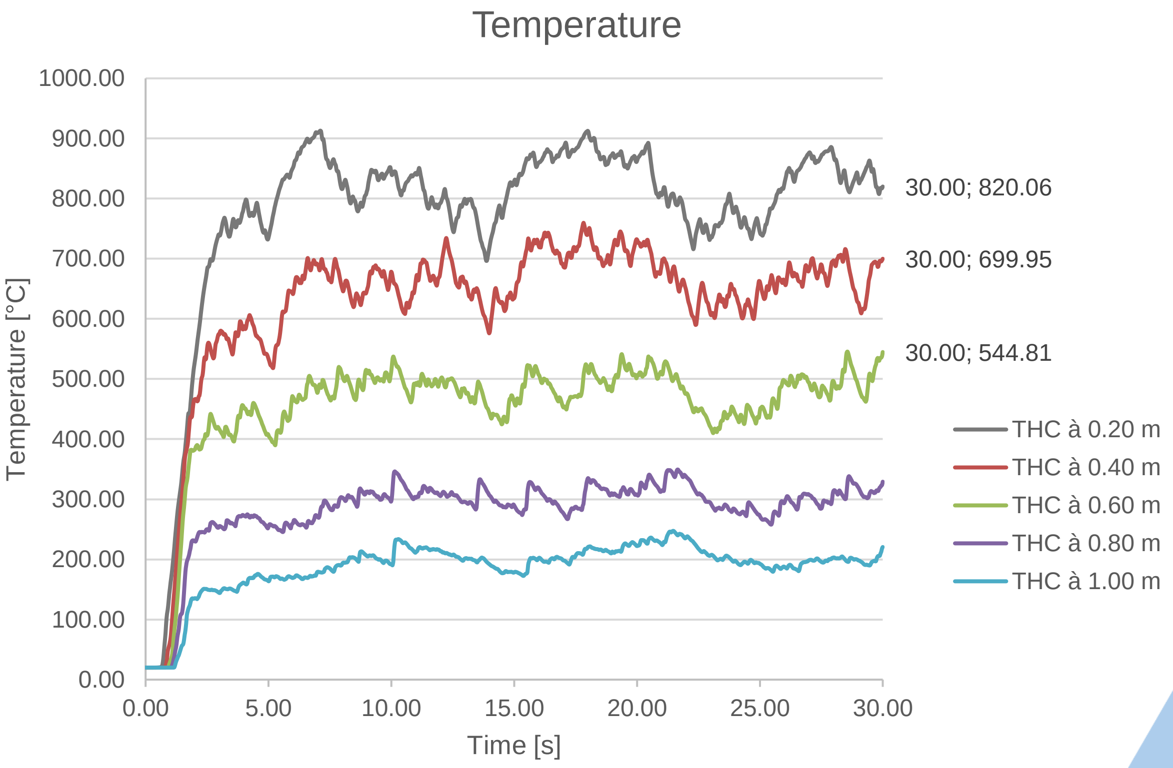


Fire Basis and Development

In fact, what is burning?

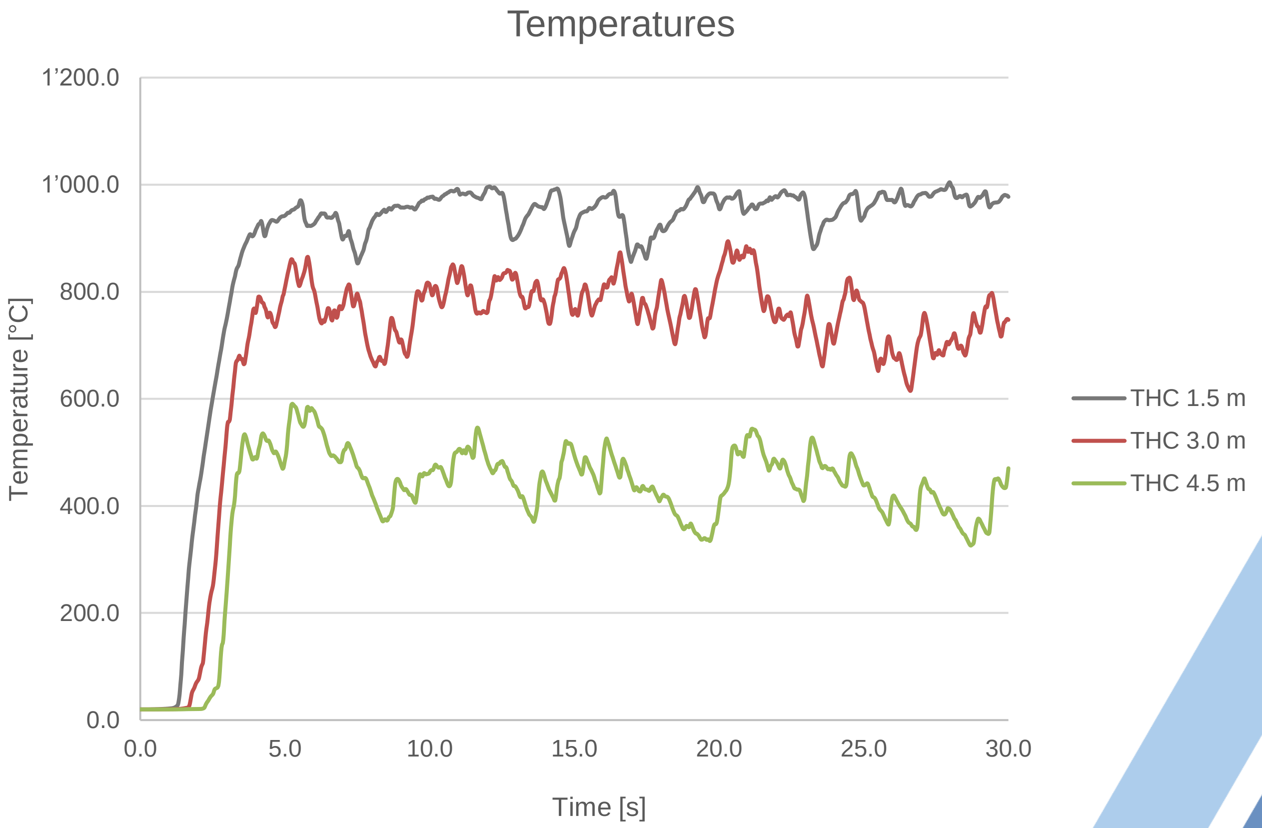
Example of fire





Epthane Fire 0.04 m^2, power ~ 45 kW

Example of fire



N-Heptane Fire, Surface $1m^2$, power ~ 3200 KW

Some famous fires

Rome in 64

Iroquois Theatre in Chicago in 1903

London in 1666

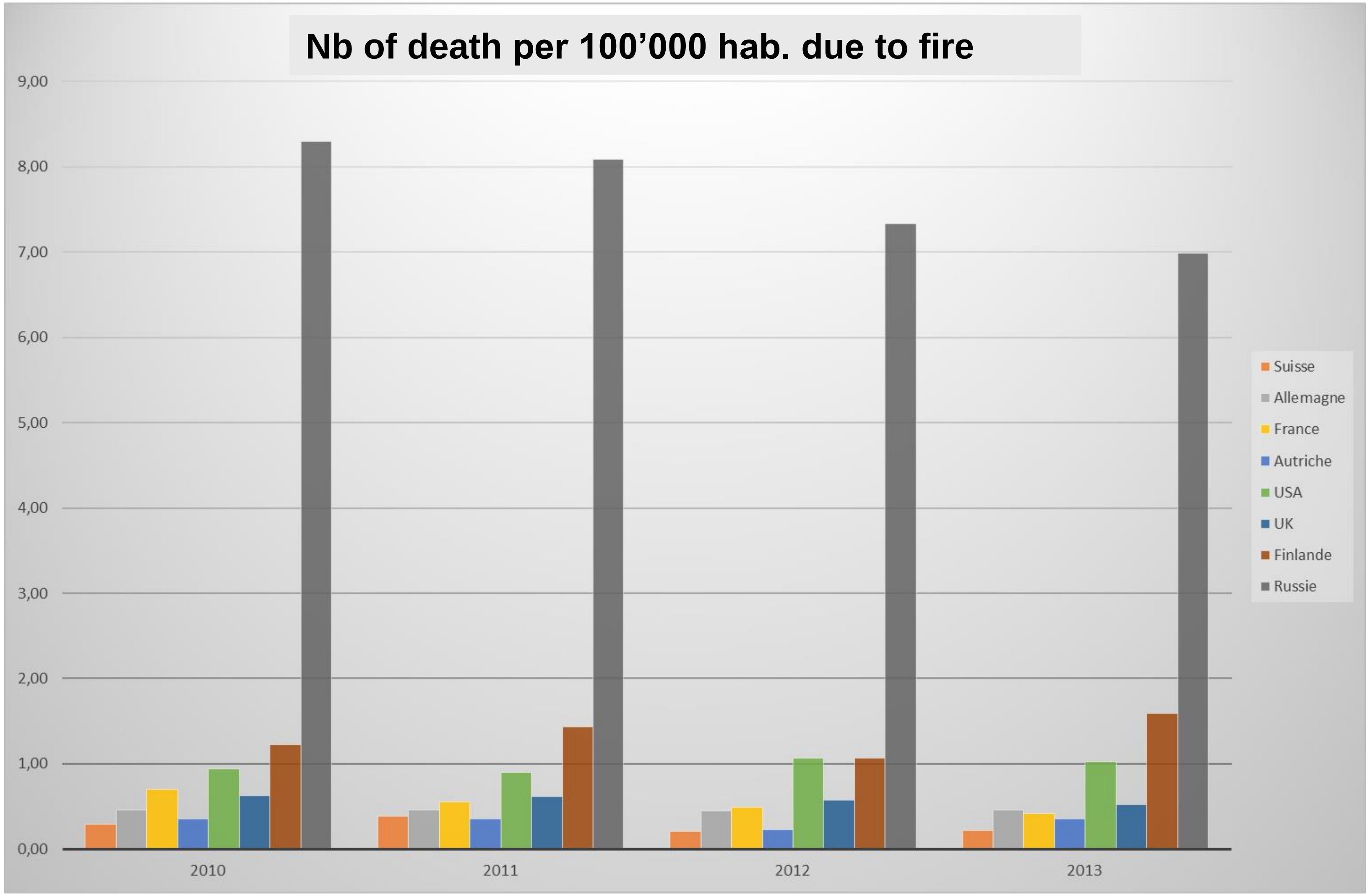
Kappelbrücke in Lucerne in 1993

Fire in Bradford Stadium (UK) in 1985

What is the risk of fire in Switzerland and around the world?

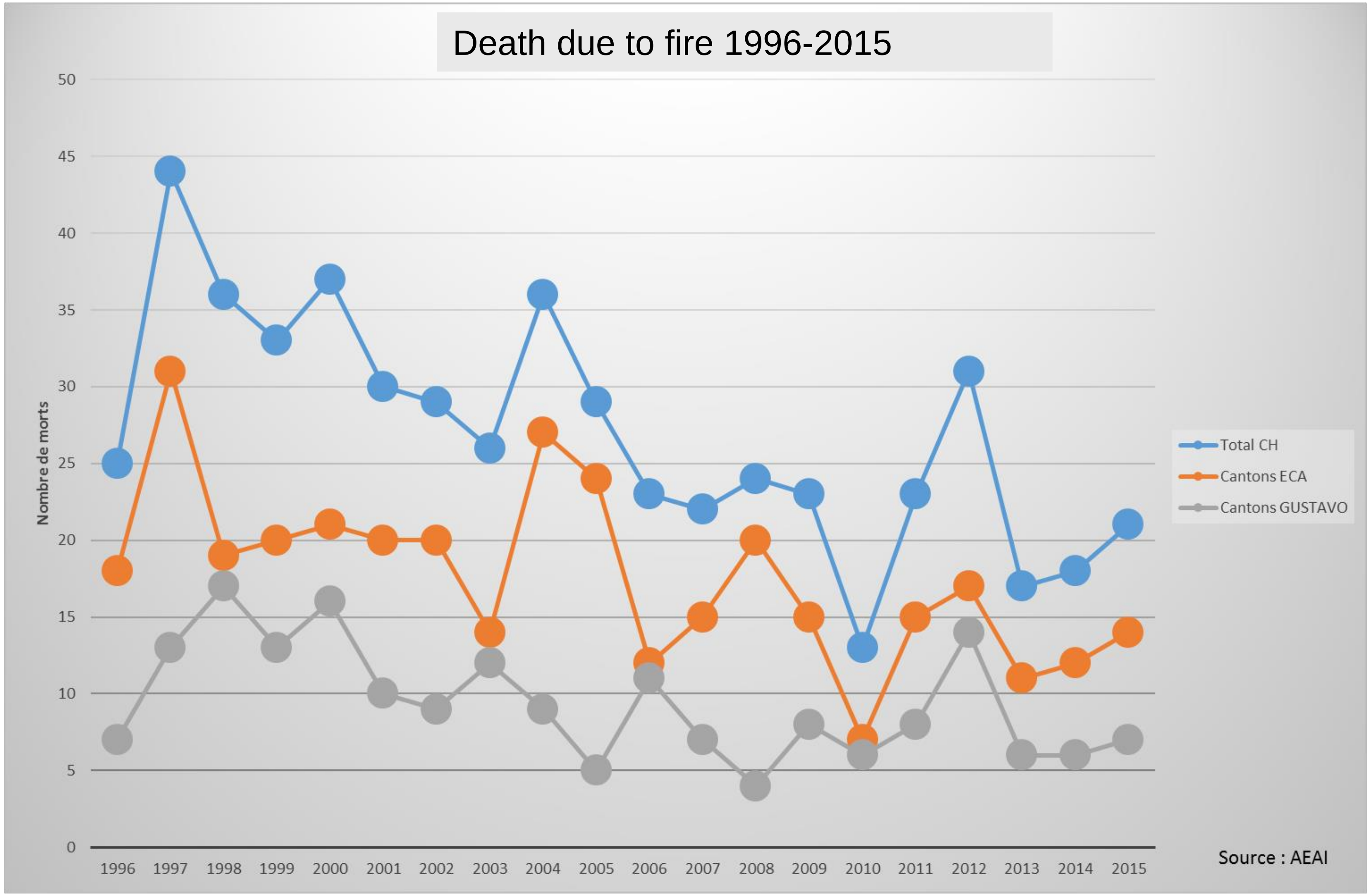
What is the risk of fire?

The fire risk of dying in a fire varies greatly



What is the risk of fire?

In Switzerland, the risk of dying in a fire is low



Medium risk:

30 cases / year in Switzerland:

p_f = 3,60 · 10^{-6} / year

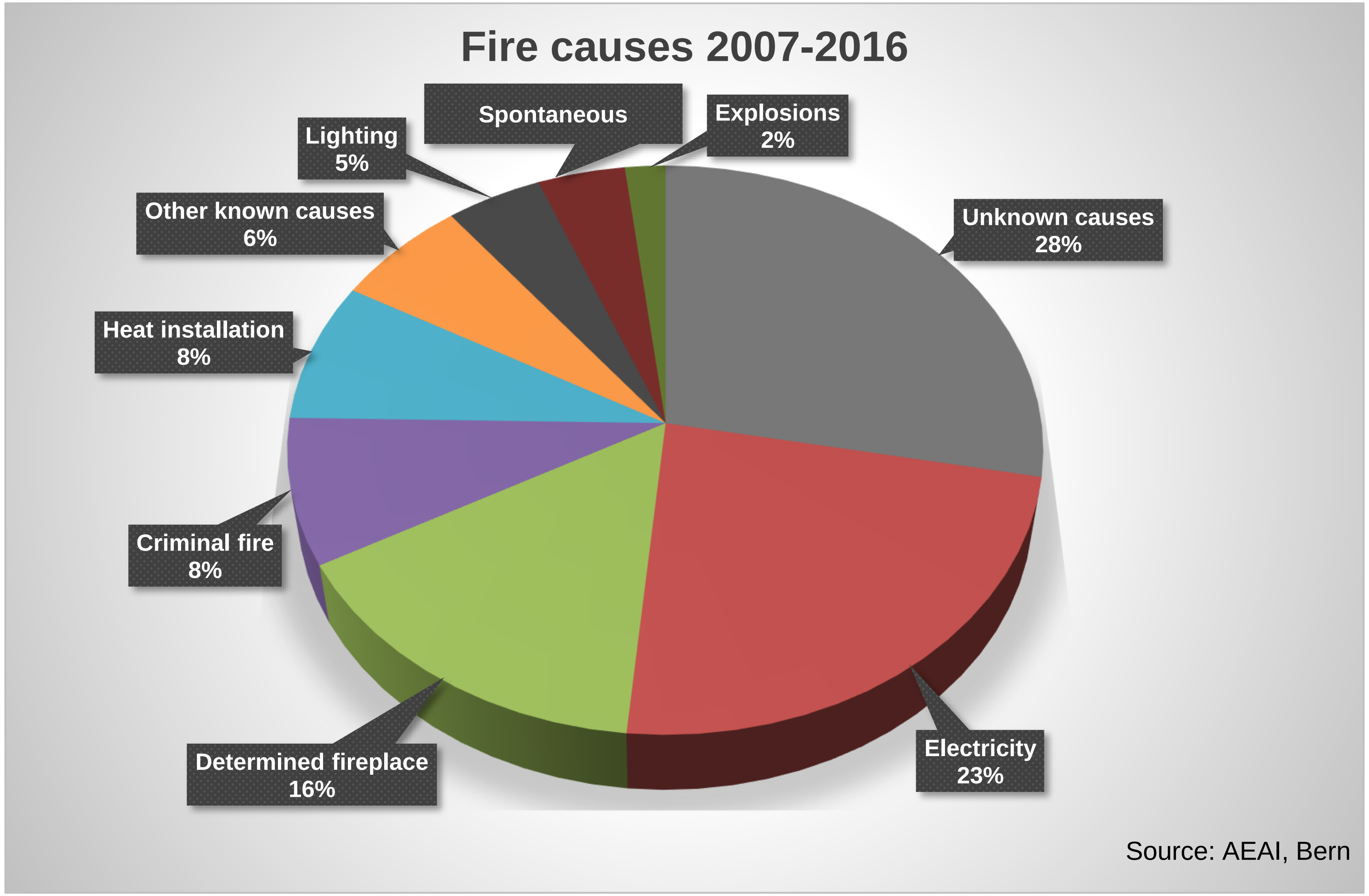
68’000 Deaths in Switzerland, 2017 :

p_f = 8.2 · 10^{-3} / year

That is 1/2300th of the deaths

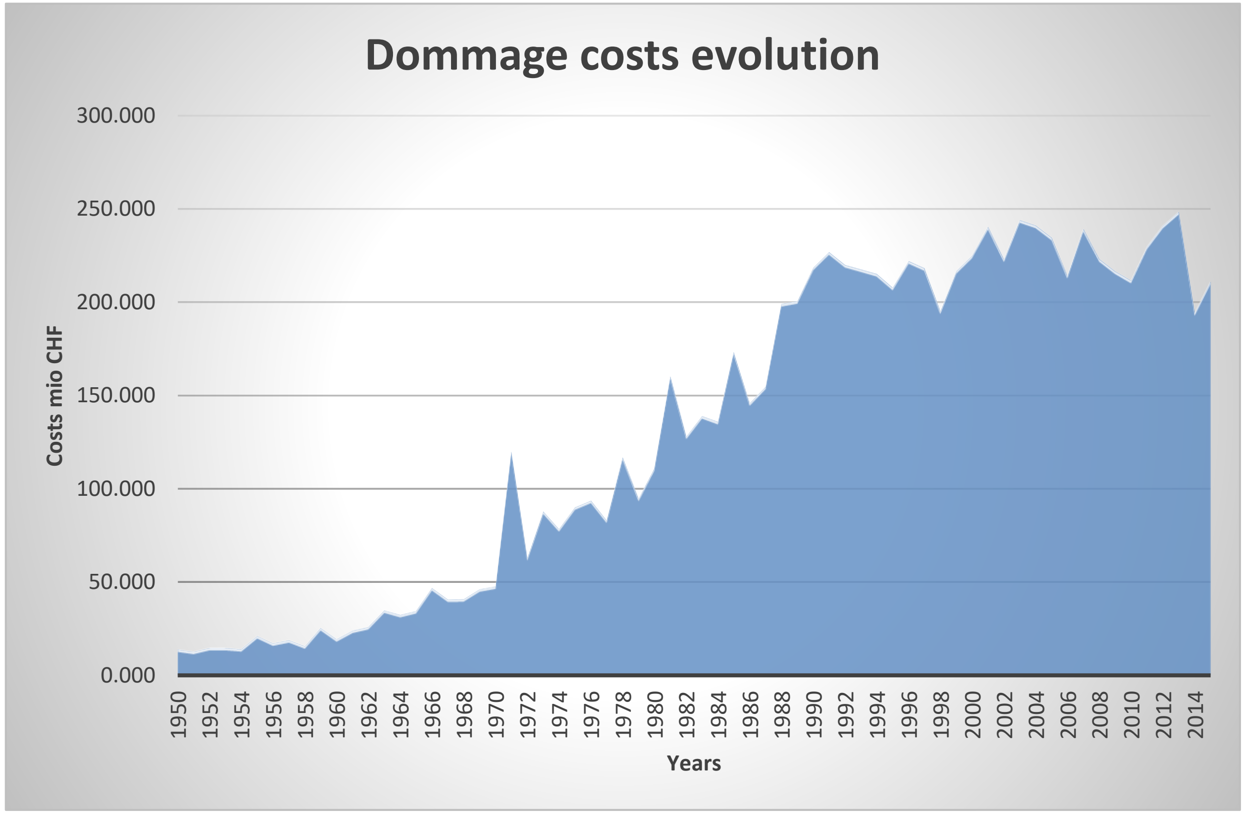
What is the risk of fire?

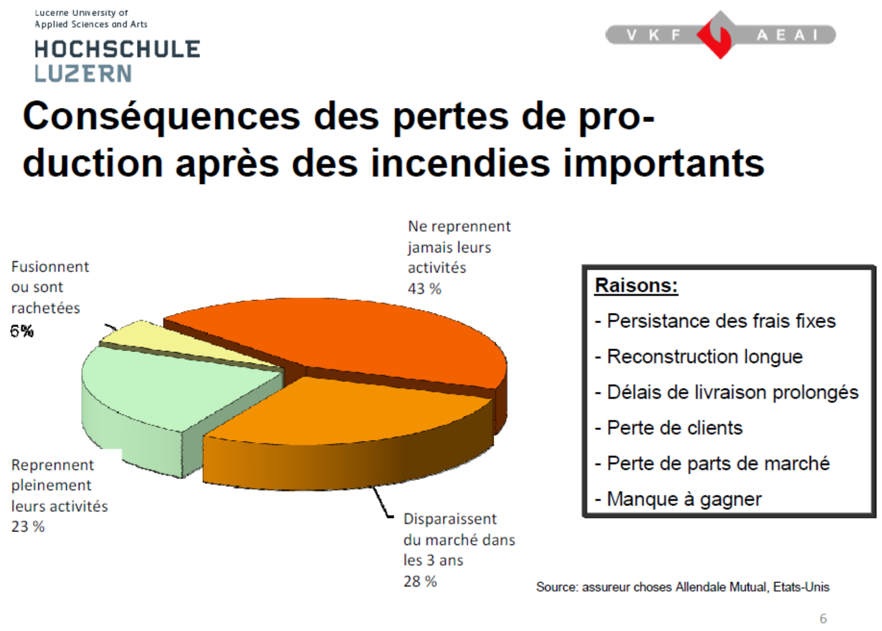
The causes of fires in Switzerland



Risk analysis

On the other hand, the economic damage is often significant



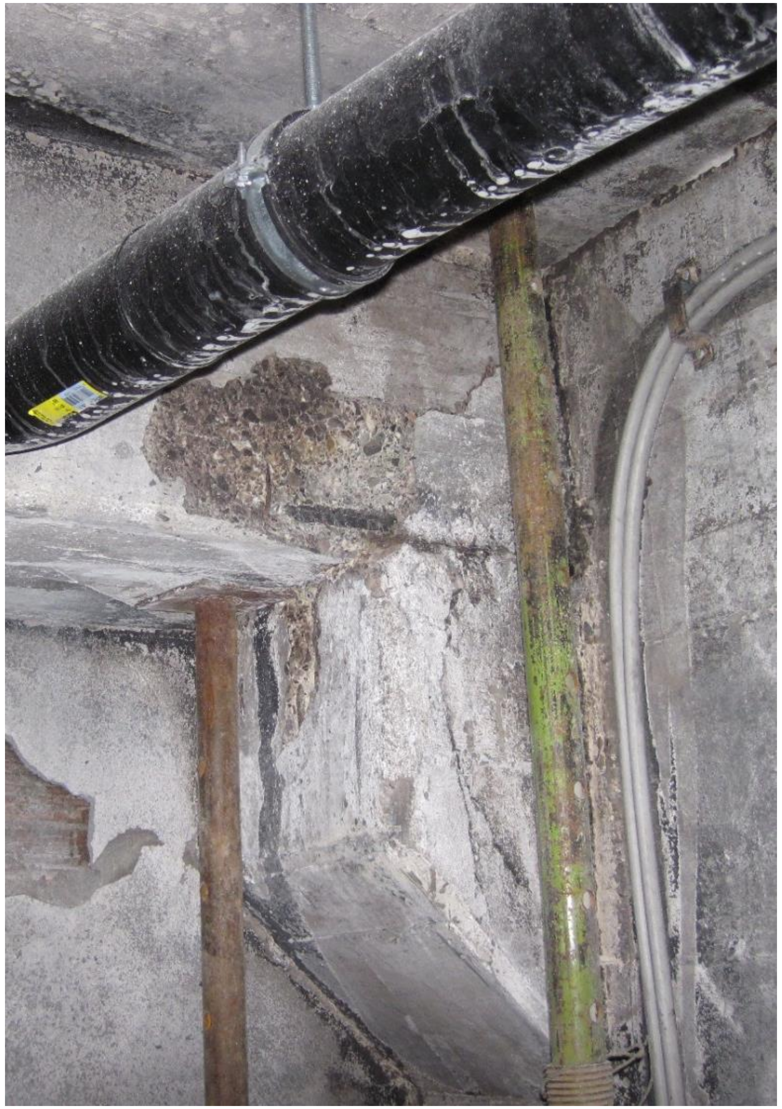


Structural Impacts

Structural Impacts

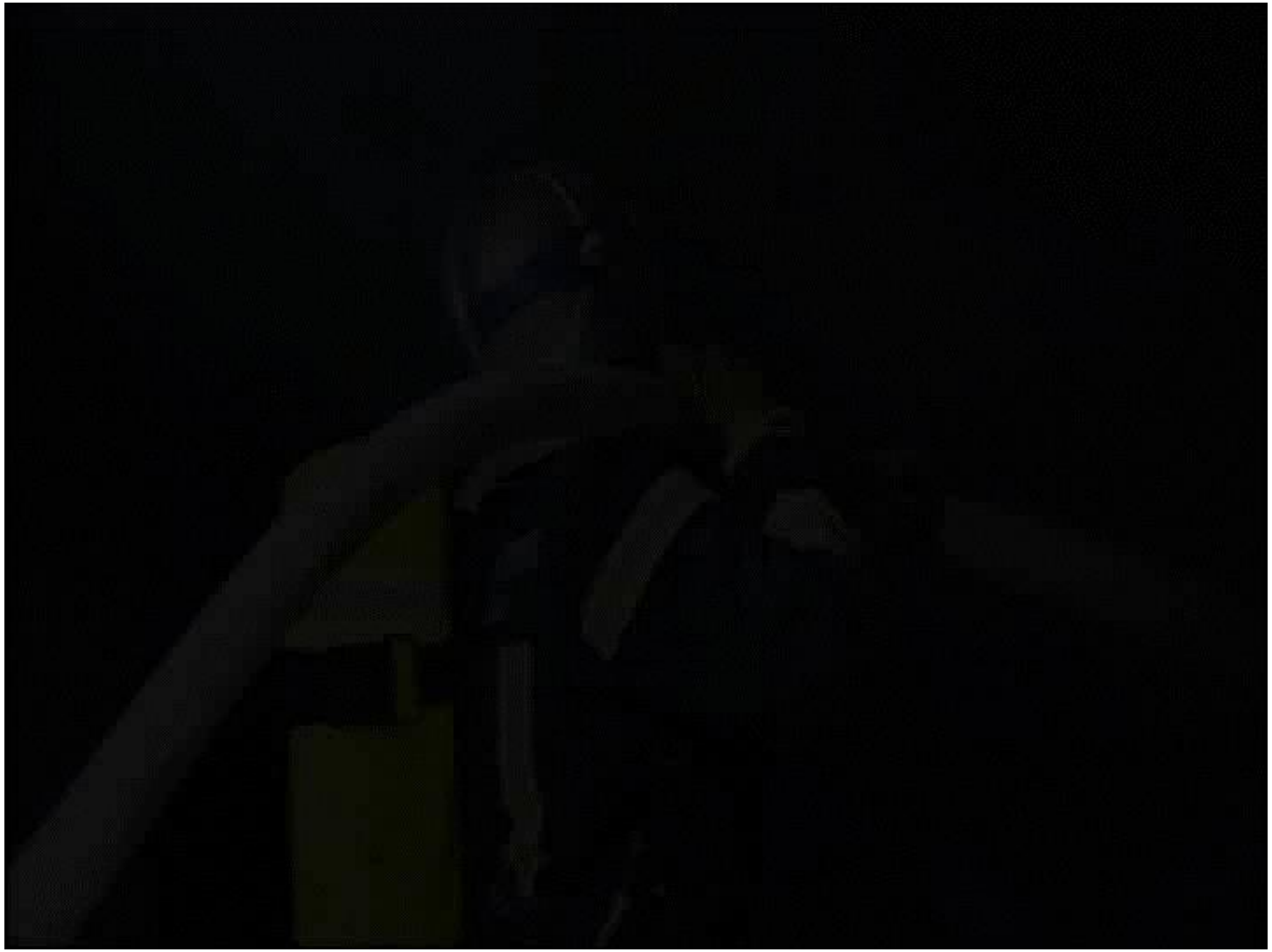
Fire in Montreux, 2011

Structural Impacts



Fire in Montreux, 2011

Structural Impacts



Fire in the Av. de Provence building in Lausanne, 2010

Structural Impacts

Fire in the Av. de Provence building in Lausanne, 2010

Structural Impacts

Gretzenbach underground garage fire, 2004

Structural Impacts

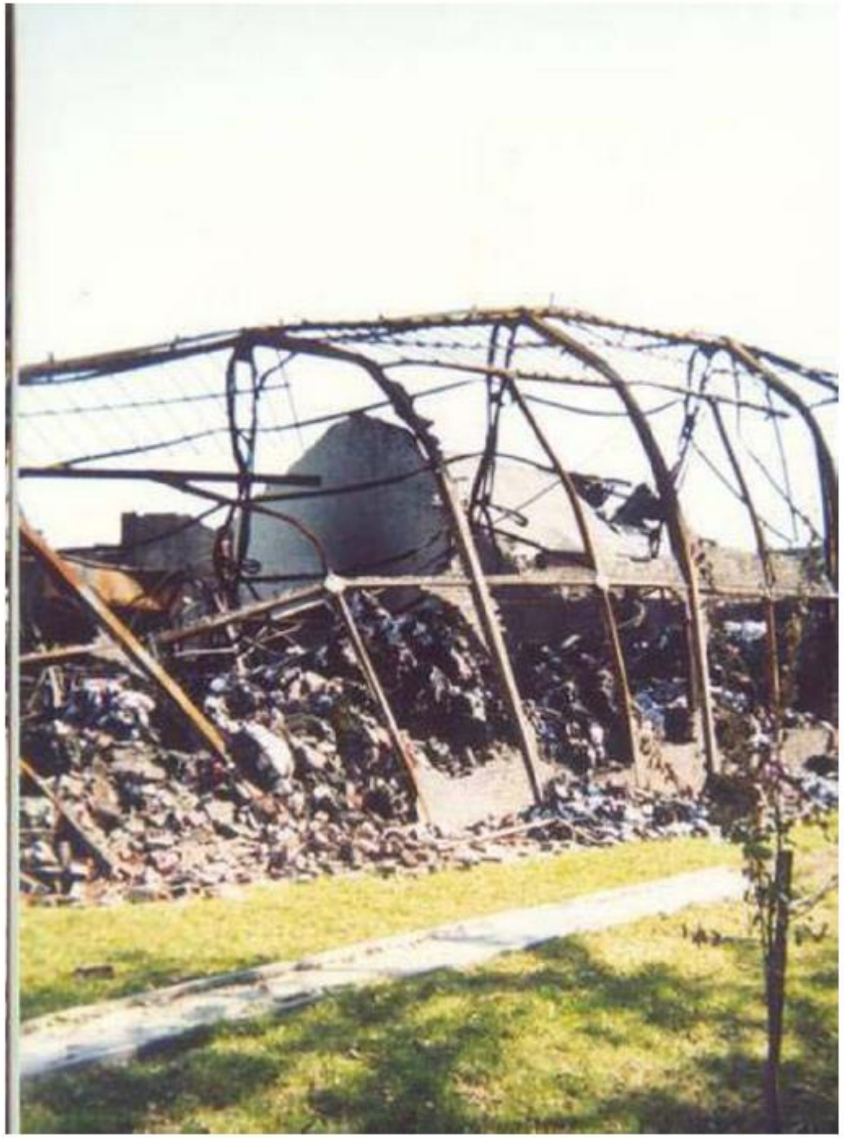


Figure 2-1 Structure en béton précontraint déversé vers l'extérieur (photo ci-dessus) et la structure en acier effondrée vers l'intérieur (photo de droite)

Structural Impacts

a) Bâtiment endommagé après le feu

b) Ruine de la structure vers l'intérieur

c) Mur coupe-feu non endommagé

d) Composantes de la structure après le feu

Structural Impacts

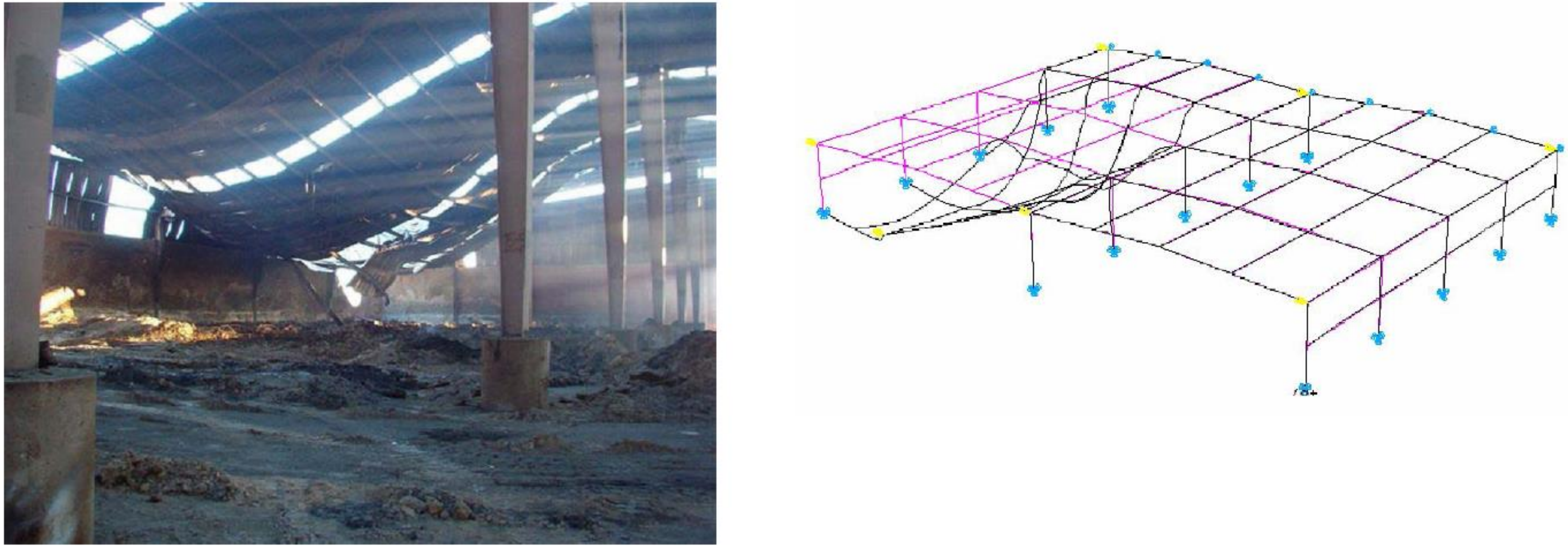
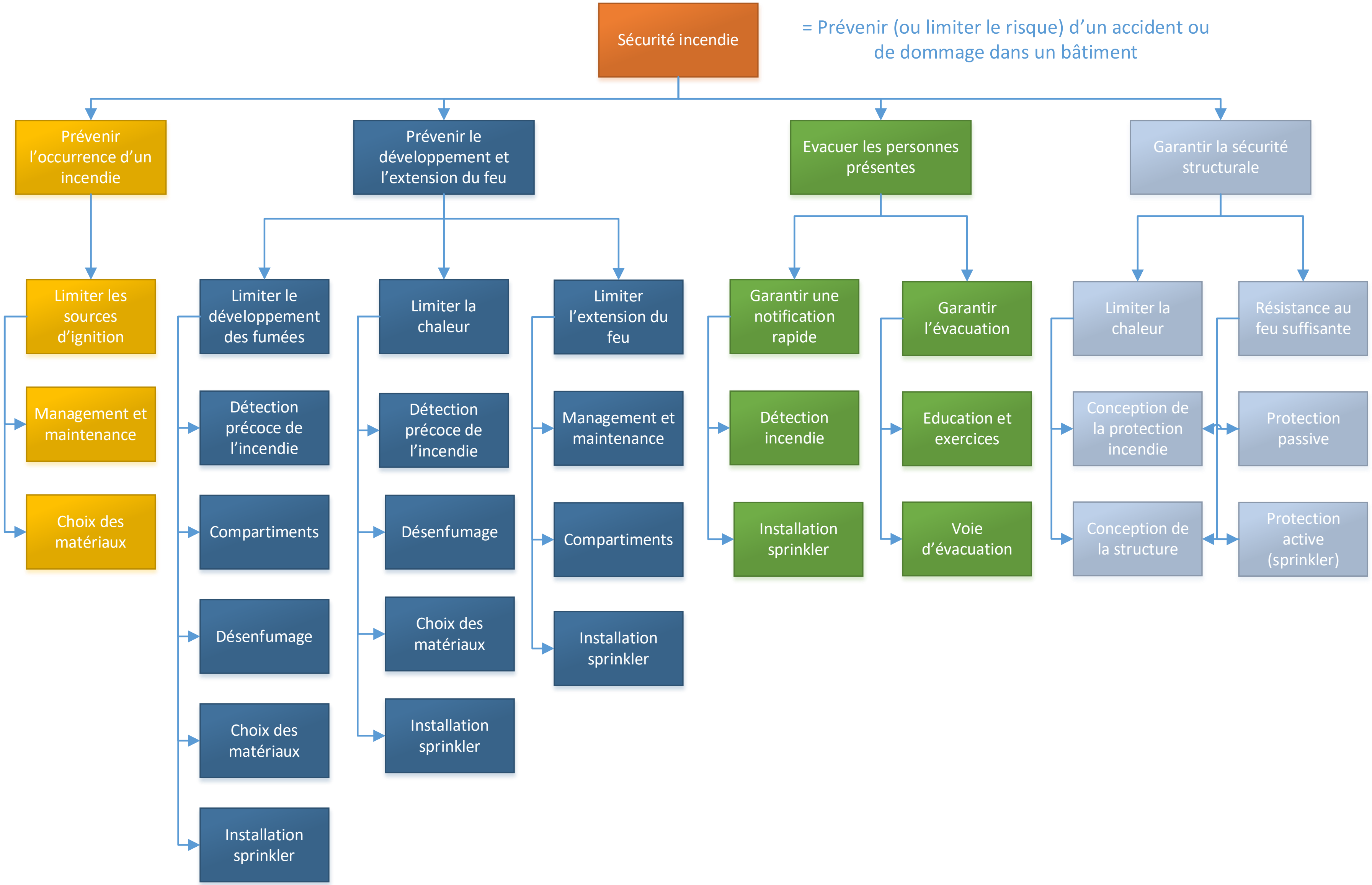


Figure 2-3 Ruine partielle (cas réel et simulation numérique)

Designing a safe building in case of a fire

Fire Safety Implementation



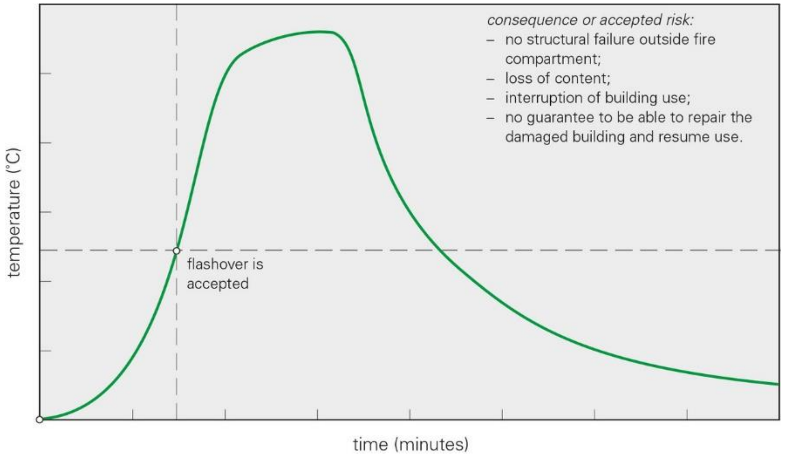
Fire Safety Implementation

Construction concept

- Compartment-based concept to prevent fire spread.
- Flashover is possible.

The following solutions are possible to achieve the objective in the case of metal structures:

- Calculation of structures in "fire" situations.
- Place the structure outside the building.
- Fill the structure with water.
- Fill or cover the structure with concrete.
- Apply an intumescent paint.
- Integration of the metal structure into walls or floors.
- Protection of the structure by insulation or plates.



Construction concept

Outdoor structures

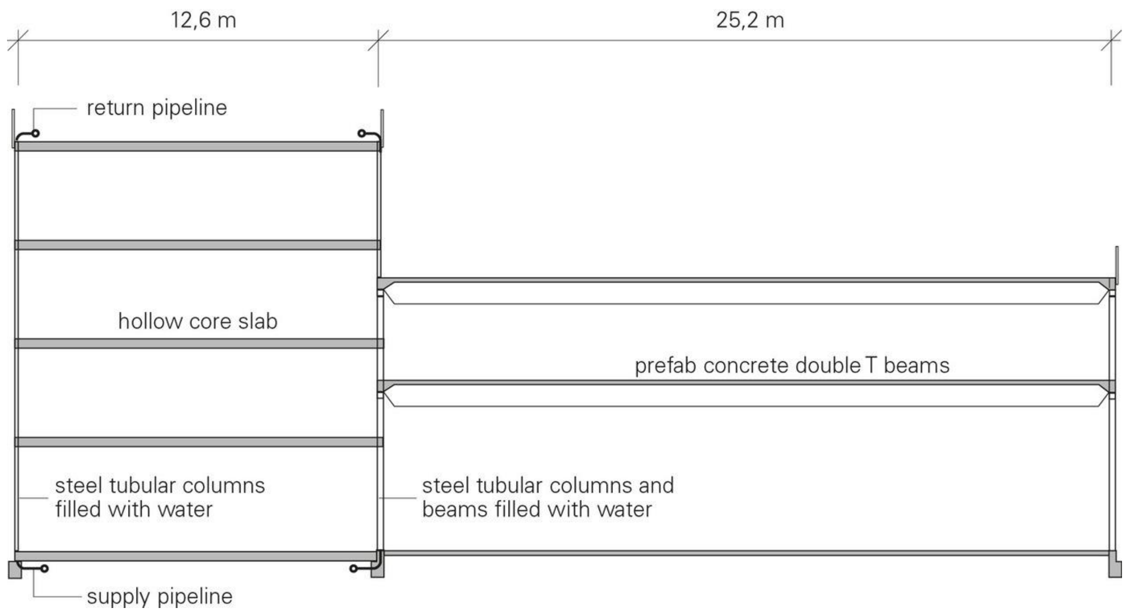
- Exterior metal profiles must also have fire resistance if they are an integral part of the load-bearing structure.
- However, the temperatures they will be subjected to are much lower than the standard ISO curve.

Construction concept

Irrigated structures

- Hollow metal profiles permanently filled with water that can circulate during the fire
- If circulation: the renewal of cold water keeps the steel at a low temperature

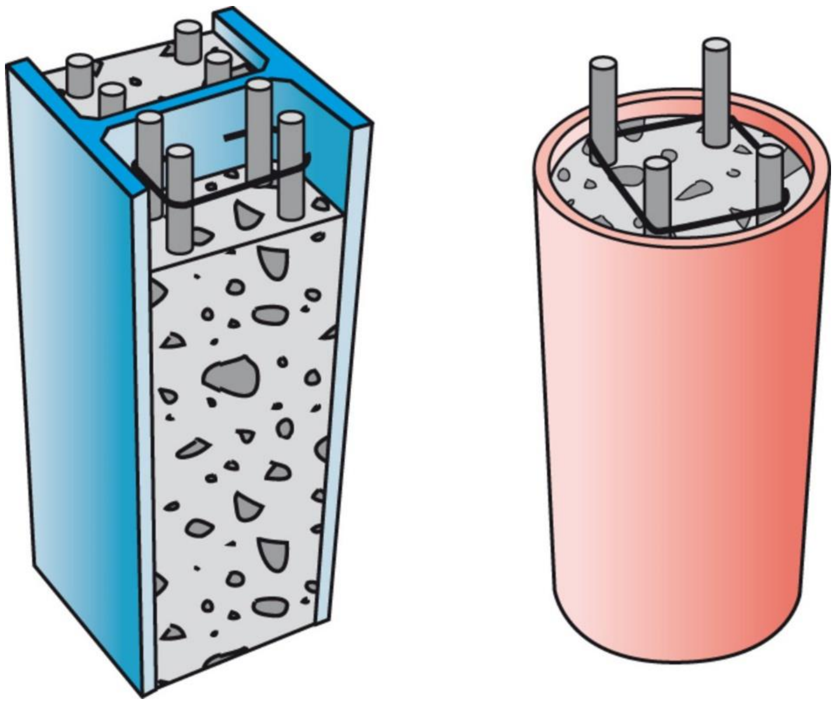
Tom de Rooij Fotografie



Construction concept

Mixed structures

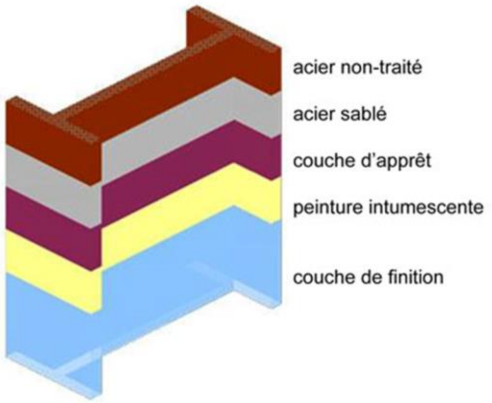
- By filling hollow metal sections with concrete or by partially filling the flanges of H-sections, the fire resistance is significantly increased.
- Hollow, slender columns filled with concrete have in most cases a resistance of 30 minutes, even without reinforcement.



Construction concept

Intumescent paint

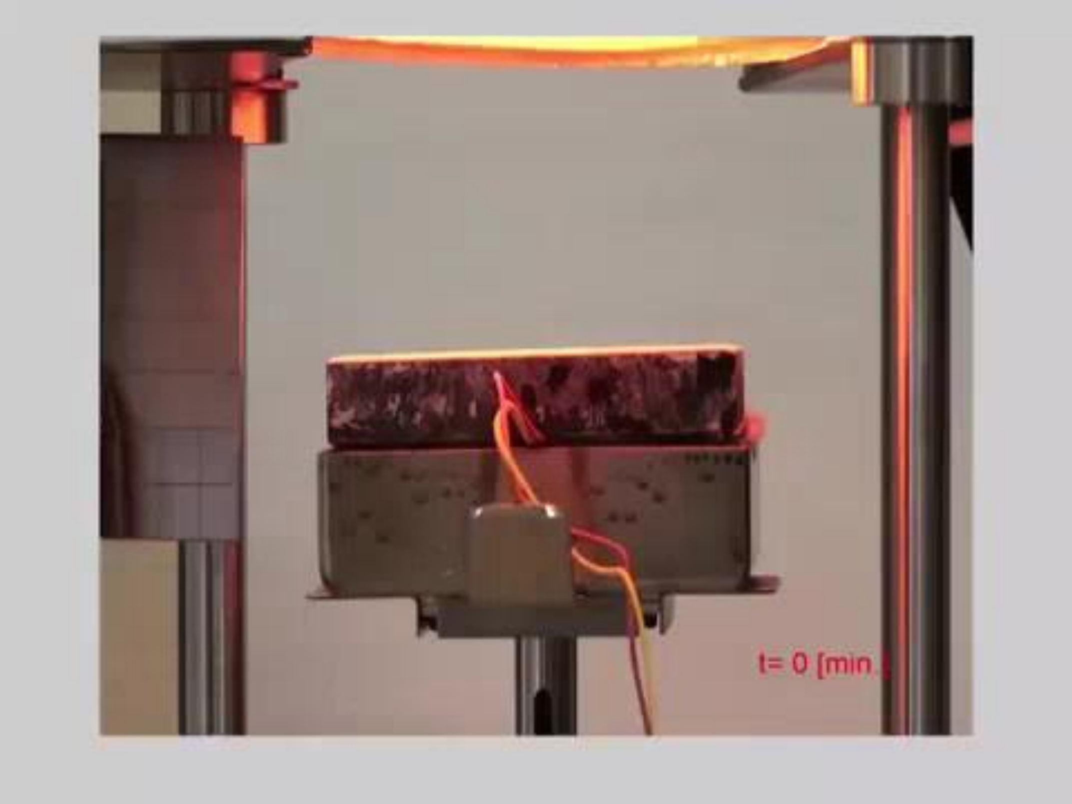
- They are suitable for steel and other ferrous materials (e.g. cast iron).
- Not for use on light alloys (e.g. aluminium).
- 1 or 2 component system.
- In Switzerland, R 30 and R 60 protection are possible.
- All paints used must be listed in the AEAI Fire Protection Directory (www.praever.ch).
- As this is a tricky system to set up and maintain, the Swiss Steel Construction Centre (SZS) has drawn up a state-of-the-art document.



Construction concept

Mode d'action

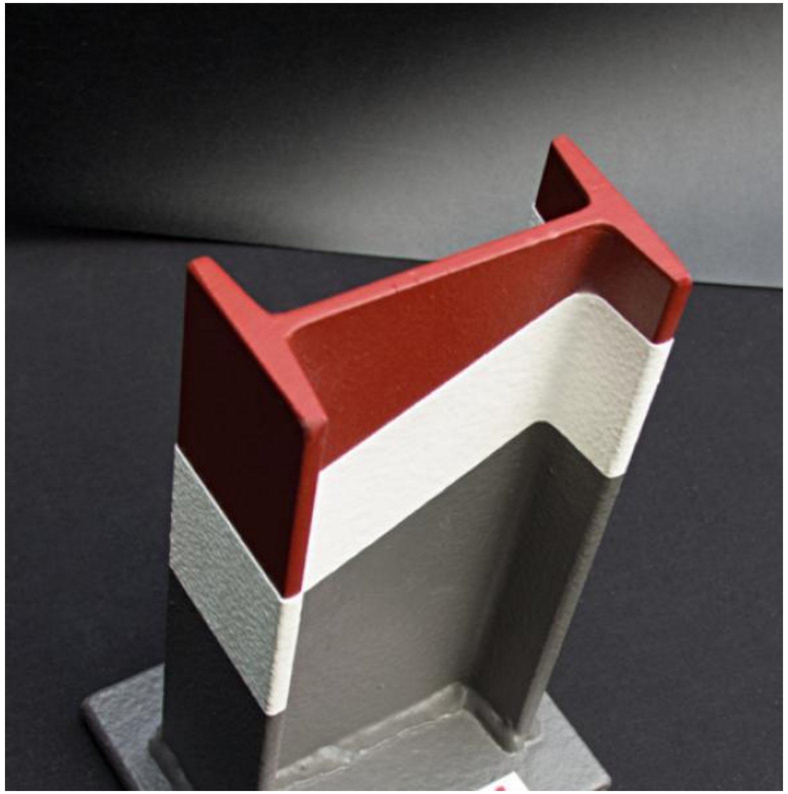
- The coatings begin to swell under the effect of heat (from 120-200 °C).
- An insulating foam is formed with a size of approx. 50 x the starting layer (max. approx. 80 mm).
- The foam insulates the profile, which reaches its critical temperature later, so the loss of strength is delayed.



Construction concept

Structure of the coating

- Intumescent paint systems consist of one to three layers.
- Before any paint application on a metal frame, a Sa 2 1/2 quality sandblasting must be carried out, in order to eliminate all traces of rust and allow a good adhesion of the paint to the steel.
- Primer layer used as an adhesion agent and corrosion protection agent (tested for the system).
- A layer of intumescent paint.
- A possible topcoat with a choice of colour (tested with the system).



Construction concept

Layer thickness

- The thickness of the layers is decisive for fire resistance.
- They depend on the following points:
  - Painting system
  - Fire resistance duration
  - Profile shape (open or closed)
  - Mass factor U/A
  - Critical temperature

- The thickness of the dry layer is decisive.
- The required dry layer thicknesses are set out in the Swiss Fire Protection Directory of the AEAI, or in the European approvals.

Construction concept

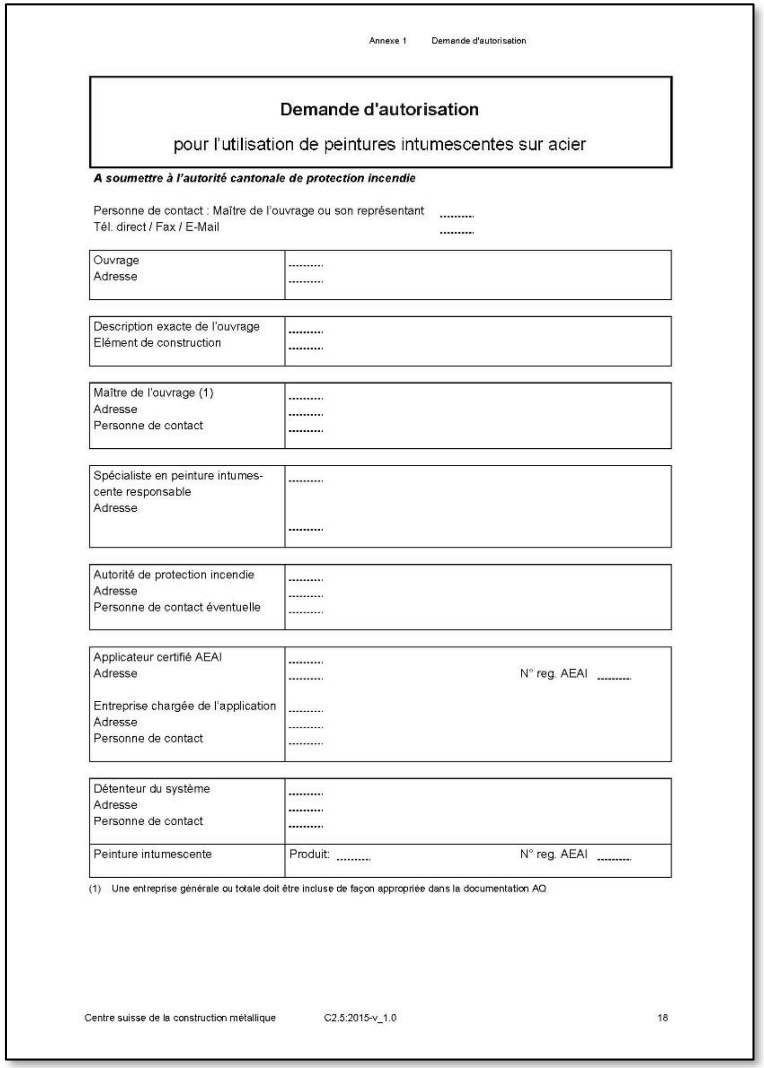
Screening

Before applying for authorization, these questions must be answered:

- Is the structure suitable for intumescent painting?
- What is the required fire resistance (R 30 or R 60)?
- Is it a new or existing structure?
- Is indoor or outdoor use planned (indication of corrosivity category according to SN ISO 12944)?
- What are the elements to be protected (indication of the exact extent of the painting work, type of profile, U/A ratio)?
- Detailed information on connections and mounting distances.
- Wish relating to the colour.

Construction concept

Application for authorization



Annexe 1 Demande d'autorisation

Demande d'autorisation

pour l'utilisation de peintures intumescentes sur acier

A soumettre à l'autorité cantonale de protection incendie

Personne de contact : Maître de l'ouvrage ou son représentant ....
Tél. direct / Fax / E-Mail ....

Ouvrage Adresse	....	
Description exacte de l'ouvrage Elément de construction	....	
Maître de l'ouvrage (1) Adresse Personne de contact	....	
Spécialiste en peinture intumes-cente responsable Adresse	....	
Autorité de protection incendie Adresse Personne de contact éventuelle	....	
Applicateur certifié AEAI Adresse Entreprise chargée de l'application Adresse Personne de contact	....	 N° reg. AEAI ....
Détenteur du système Adresse Personne de contact	....	
Peinture intumescente	Produit:	N° reg. AEAI ....

(1) Une entreprise générale ou totale doit être incluse de façon appropriée dans la documentation AQ

Centre suisse de la construction métallique C2.5:2015-v_1.0 18

- The use of an intumescent paint system is subject to prior approval from the fire protection authority.
- Before implementation, the written authorisation of the cantonal fire protection authorities must be presented.
- The form to be filled in is Annex 1 of the SZS C 2.5:2017 guideline.

Construction concept

Fire Safety & Engineering SA

Planning

- A distance of 50 x the thickness of the dry layer, but a maximum of 80 mm must be observed.

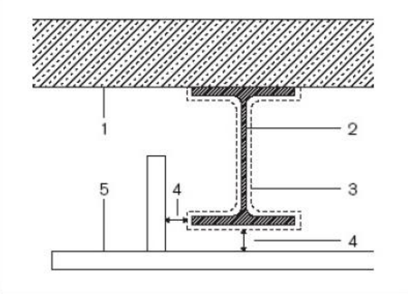
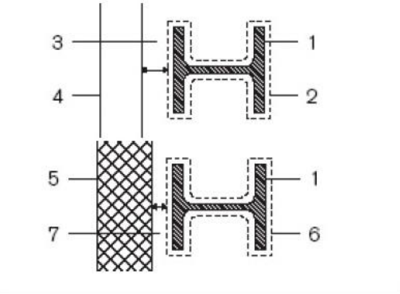
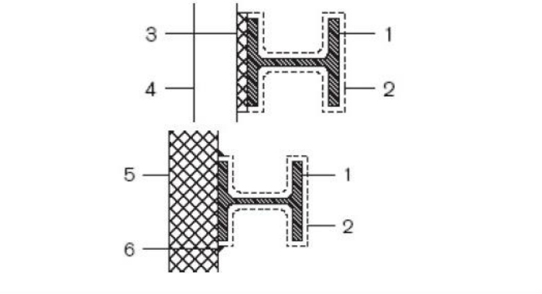
		

Fig. 1 Espaces libres pour gonflement libre de la peinture intumescente: exigences géométriques pour les poutres 1 dalle en béton 2 poutre en acier 3 peinture intumescente 4 espace libre 5 faux-plafond, chemins de câbles et similaires	Fig. 2 Espace libre pour gonflement libre de la peinture intumescente: exigences géométriques pour les poteaux (s'applique par analogie aux poutres) 1 poteau en acier 2 peinture intumescente 3 espace libre : distance selon h) 4 façade (ou paroi intérieure) 5 élément de construction avec même résistance au feu R que le poteau 6 peinture intumescente sur 4 côtés 7 espace libre, application difficile (distance selon h) ou selon fig. 3	Fig. 3 Montage contre la façade ou un élément de construction avec résistance au feu: variantes pour poteaux (s'applique par analogie aux poutres) 1 poteau en acier 2 peinture intumescente 3 plaque de protection incendie avec même R que le poteau 4 façade (ou paroi intérieure) 5 façade ou paroi intérieure avec même résistance au feu R que le poteau 6 év. joint d'angle avec mastic de protection incendie

Construction concept

Planning

- In the case of dovetail-ribbed profiled sheet (Holorib HR51), the upper side of the profile wing may remain unprotected.
- In the case of open-ribbed profiled sheet, the top surface must be protected or filled with fire protection material (RF1).

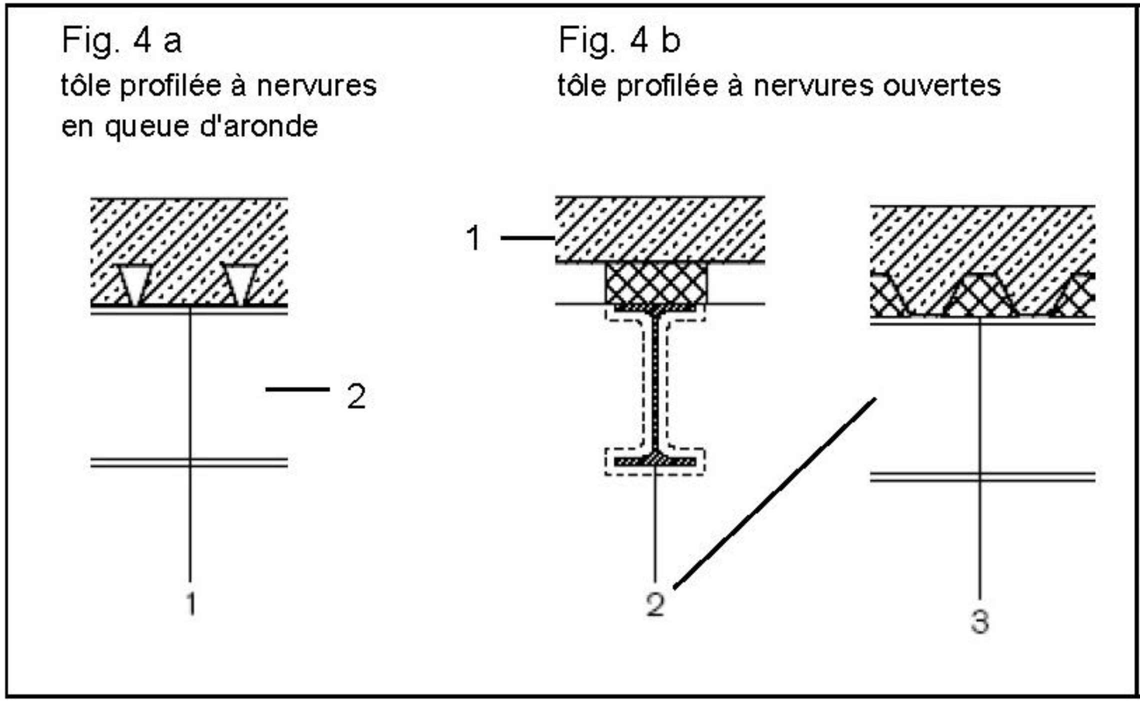


Fig. 4 a Aile supérieure non protégée (autorisé seulement en cas de tôle profilée à nervures en queue d'aronde)

1 dalle mixte acier-béton avec tôle profilée
2 poutre en acier (peinture intumescente sur 3 côtés)

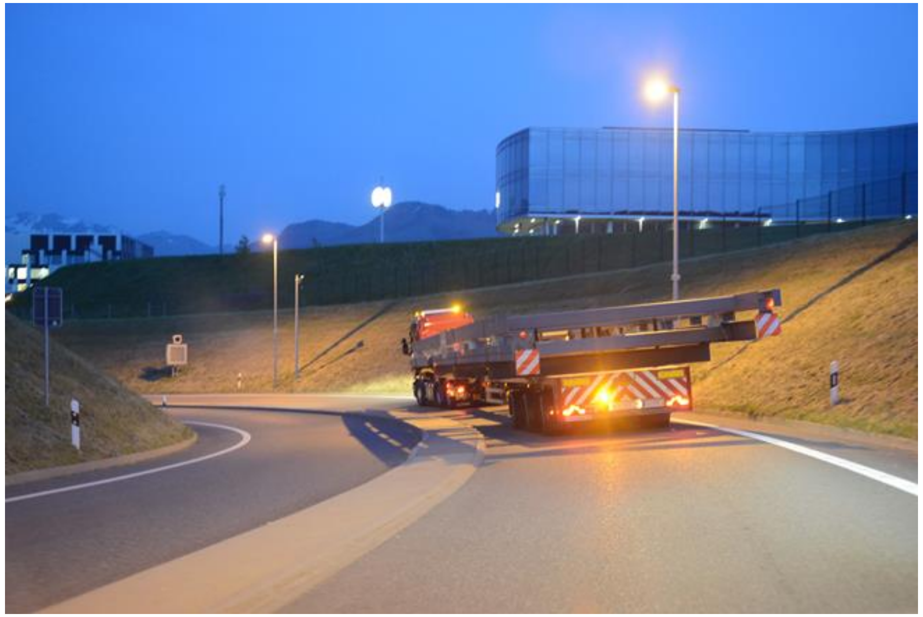
Fig. 4 b Les ailes supérieures doivent être protégées en cas de tôle profilée à nervures ouvertes

1 dalle mixte acier-béton avec tôle profilée
2 poutre en acier (peinture intumescente sur 3 côtés)
3 remplissage avec matière de protection incendie, par ex. laine minérale

Construction concept

Application Steps

- Application of the primer layer and thickness measurement (normally in the workshop).
- Transport of the elements of the framework on site and assembly.
- Repair of damage to the base layer.



Construction concept

Application Steps

- Measurement of climatic conditions during application and at least 3 times per day. If the required conditions are not met, the application must be stopped.
- Application of intumescent paint.
- Measurement of wet thickness using a measuring comb.

Construction concept

Application Steps

- Complete control that all surfaces are well coated according to the fire protection plan.
- Measurement and recording of dry thicknesses in general by an expert external to the applicator.
- Application of the topcoat compatible with the system.
- No further paint should be applied afterwards except for repairs with an approved product.

Construction concept

Example

Two two-storey industrial halls with unknown use:

- Requirements REI 60 for composite floors and R 60 for columns.
- Mixed floors with a surface area of 1,800 and 3,700 m^2.
- Partial protection of the framing profiles with intumescent paint.
- Application of a 1K paint in the workshop.

Construction concept

Industrial hall in Puidoux

Construction concept

This type of damage is inevitable with a 1K paint job in the workshop. This is why it is preferable to apply it on site or use a 2K paint (more expensive, but less time spent on site).

Layer thickness control is very important. In this case, it was not compliant: almost 50% of the thickness was missing!

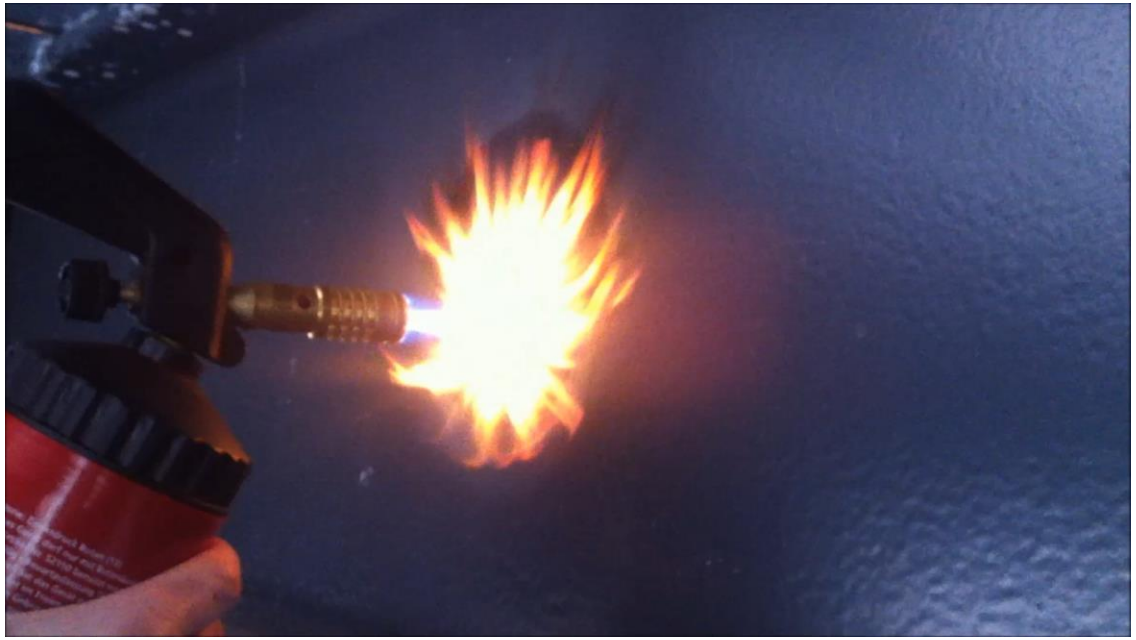
Construction concept

- Bad luck, the applicator has already applied the finishing layer! What do we do?
- Indeed, you can't put a layer of intumescent paint back on after the top varnish!
- In the meantime, this is what has been done without any agreement.
- So refusal of the expert and the fire protection authority of this state of affairs

→ no permit to use!

Construction concept

On-site testing to prove the intumescent power. It works, but are we sure that it is really an R 60 protection?



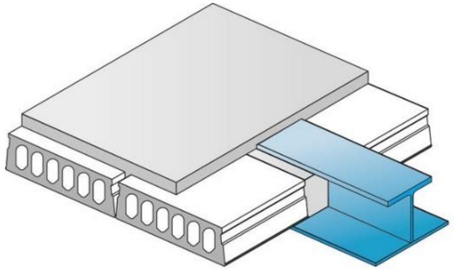
Laboratory testing (TU-Braunschweig) of test plates identical to the layers on site.

- Ouf ! The results are good because the varnish layer is fortunately very thin, no need to strip the entire framework.
- The result: significant costs for tests and delays on the construction site.

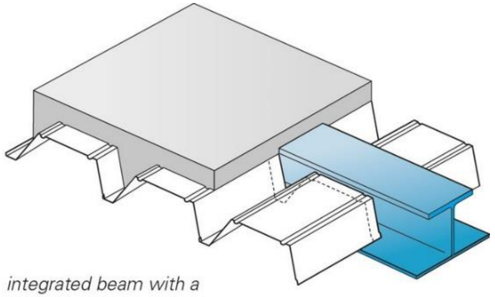
Construction concept

Integration of structures

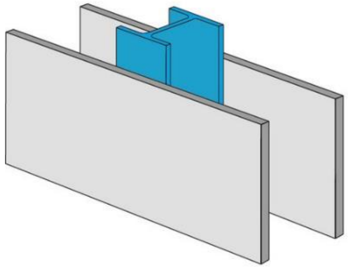
- Metal structures partially or fully integrated into the building elements.
- The advantage is that fire protection is almost free. On the other hand, the structure is hidden...



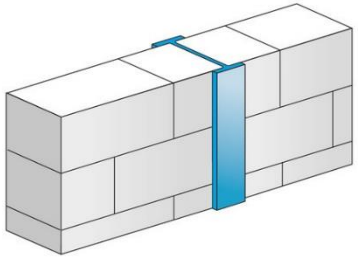
integrated beam with a hollow core slab



integrated beam with a deep composite slab



column in a (metal stud) wall



column in a masonry wall

Construction concept

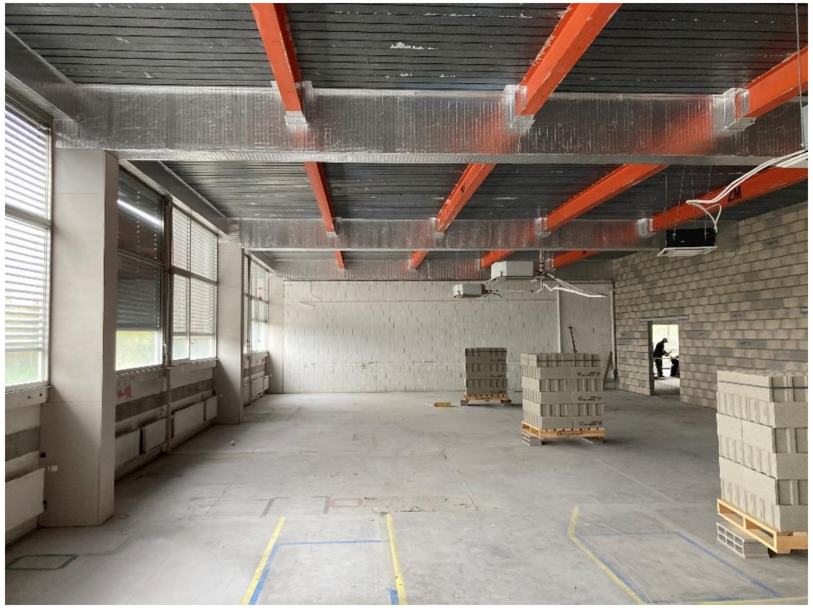
Sprayed products (flocking)

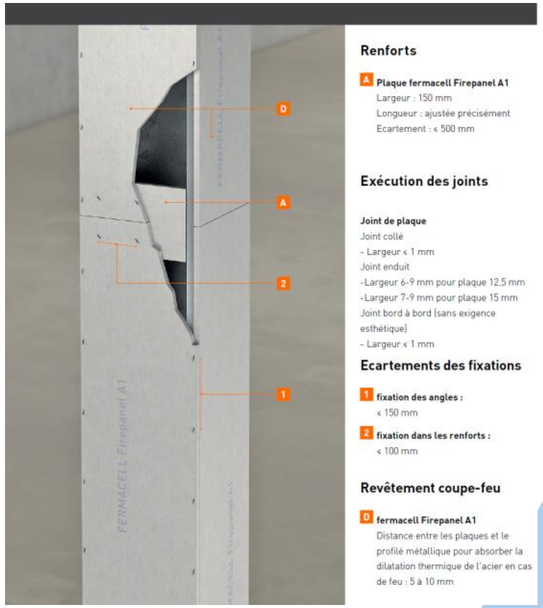
- Composed of expanded vermiculite, plaster or mineral fibres agglomerated by a binder
- Applied in several coats and dried
- Fire resistance up to 240 minutes (20 to 50 mm)

Construction concept

Sheet Products

- Based on plaster, vermiculite, mineral fibres or sand-lime compounds, thickness according to the product's performance declaration.
- Specially designed stone wool insulation for this use
- A box is built around the element to be protected
- Mechanical fixing or gluing (with fire-resistant glue!)

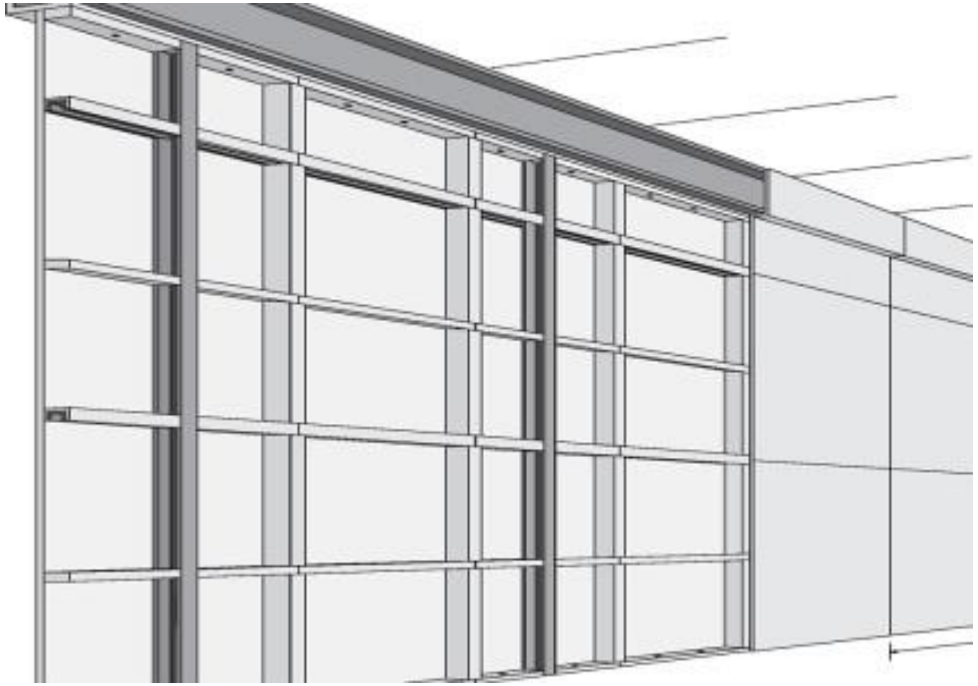




Construction concept

Screen protection

- Suspended ceilings or partition panels that significantly slow down the heating of the structure
- Special care to be taken with joints and fasteners

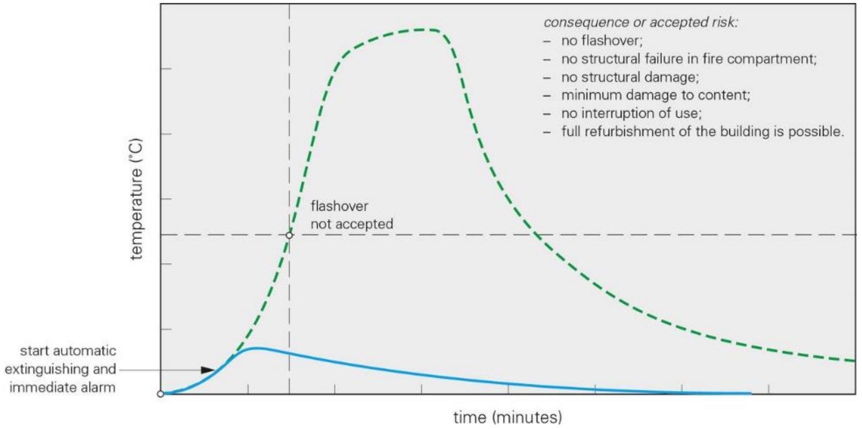


Fire Safety Implementation

Extinction concept




- Concept based on an automatic extinguishing system with water (sprinkler) or other extinguishing agents.
- The firefighters are also alarmed.
- Flashover is normally not possible.
- The purpose of the concept of "extinction" is to:
  - Extinguishing the fire at an early stage.
  - Head activation between 68 and 140 °C.
  - The temperature in the compartment remains low (< 300 °C).
  - It is possible to reduce the fire resistance requirement of the structure.



Fire protection requirements

Fire protection requirements

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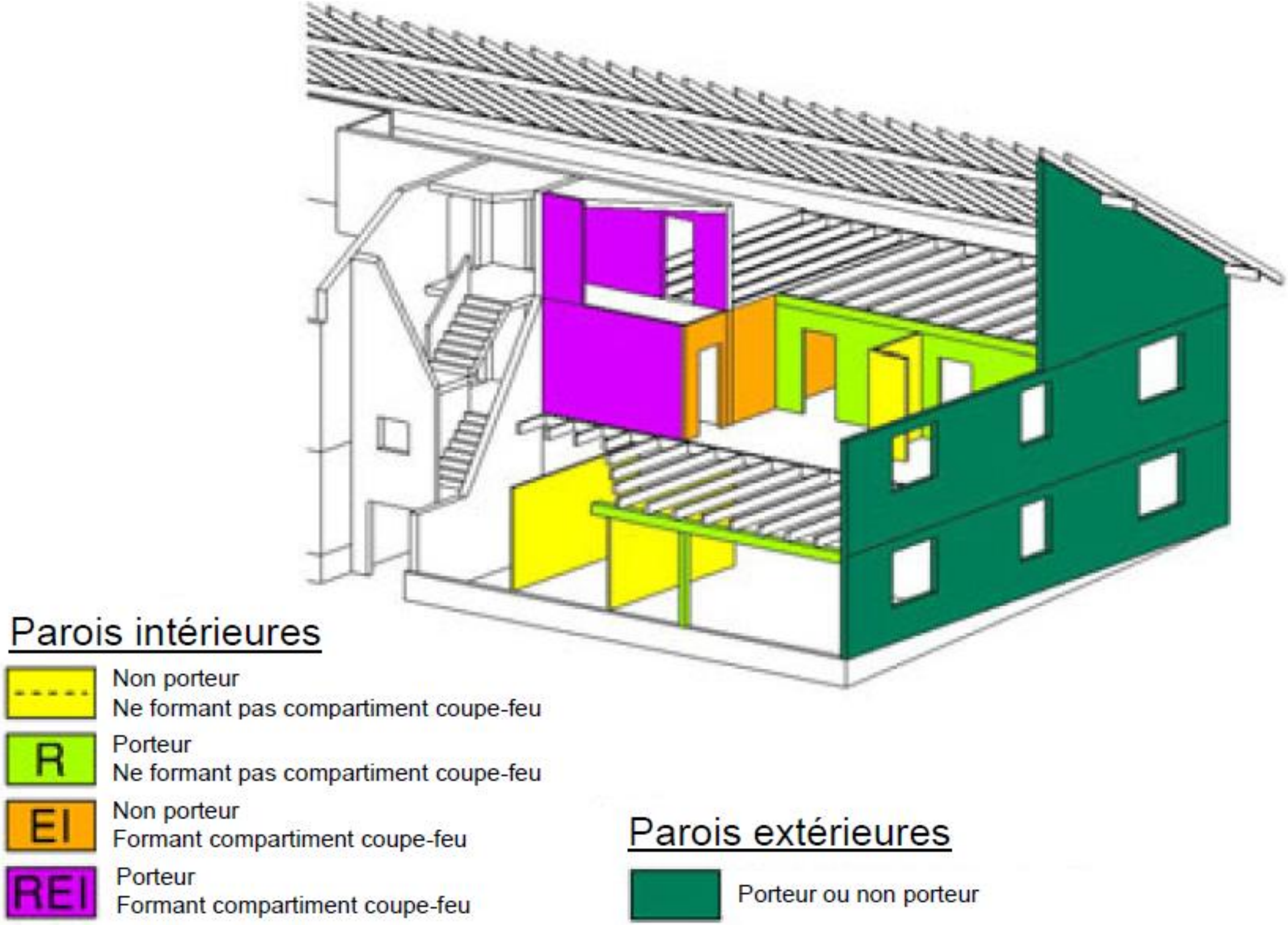
Fire Resistance Criteria

R = Resistance :	ability of the load-bearing structure to resist fire.
E = Airtightness :	Flame and hot gas tightness criteria.
I = Isolation :	thermal insulation criterion on the non-exposed side, maximum difference 140°C on average and 180°C locally.
W = Radiation :	thermal insulation criterion in terms of radiation< 15 kW/m^2 at 1.00 m on the unexposed side.

Without any particular indication, the resistance time requirement refers to the "standard" ISO curve

Example Requirements



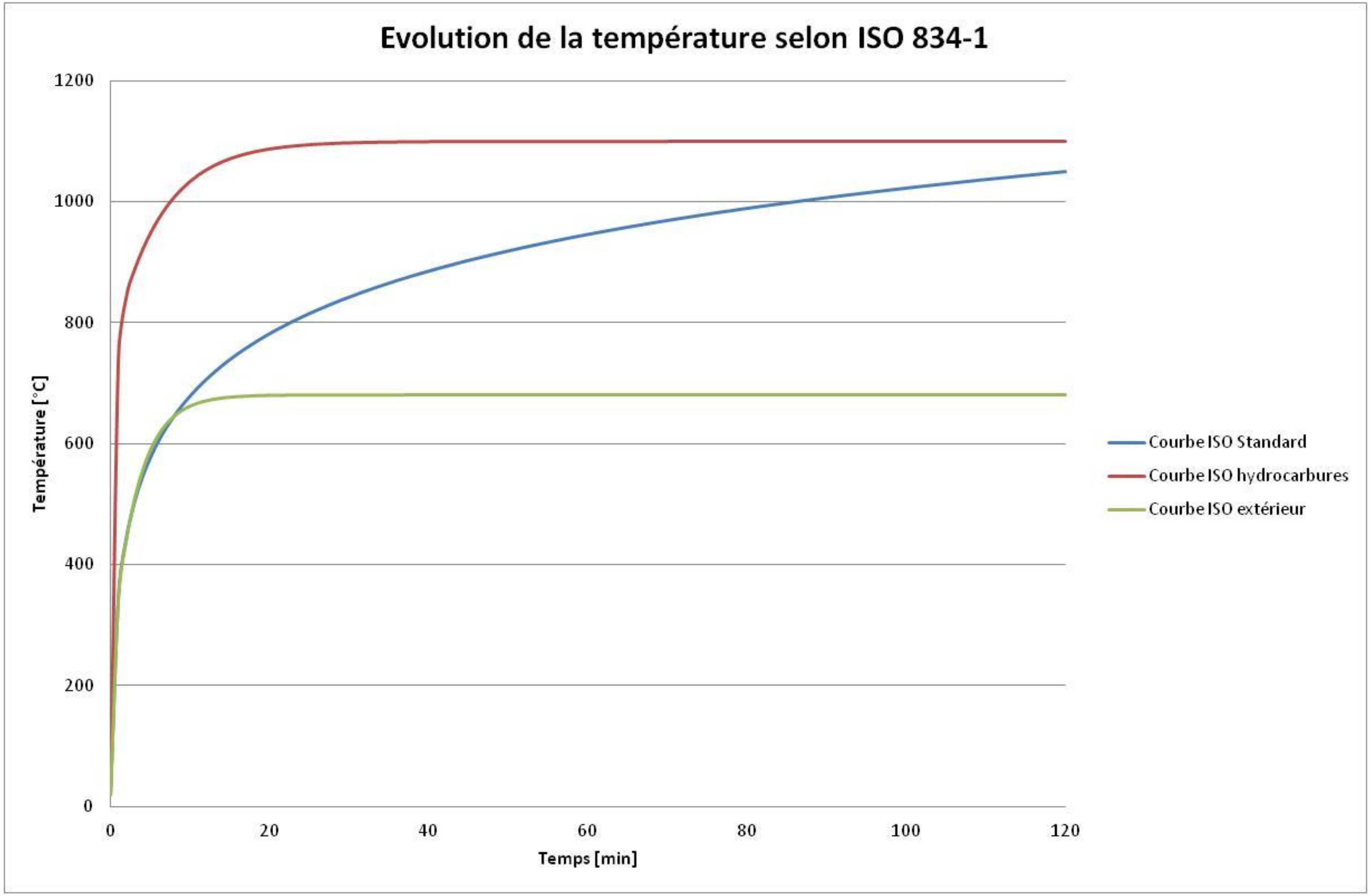
ISO Curves

The various construction standards frequently refer to one of the ISO curves (according to ISO 834).

- Normalized curve (standard)
  - $\theta_g = 20 + 345 \cdot \log_{10}(8 \cdot t + 1)$
- Hydrocarbon curve
  - $\theta_g = 20 + 1080 \cdot \left(1 - 0.325e^{-0.167t} - 0.675e^{-2.5t}\right)$
- Outdoor Fire Curve
  - $\theta_g = 20 + 660\left(1 - 0.687e^{-0.32t} - 0.313e^{-3.8t}\right)$

θ_g: Gas temperature [°C]
t: time [min]
The convection heat transfer coefficient must be 25 W/m^2K for calculations with this type of curve.

ISO 834 curves



ISO Curve

Some remarks on the "standard" ISO 834 curve

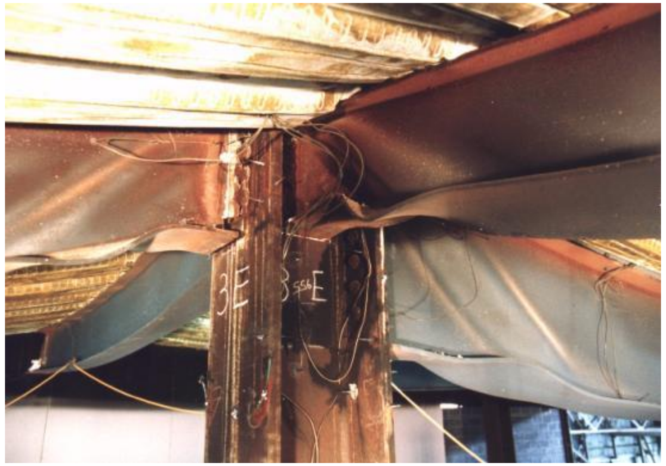
- The temperature only increases over time
- The amount of fuel is infinite
- This curve is not a curve established by measurements taken during real fires.
- It stems from the thermal regime that was established in the first test furnace built at Columbia University in the early 20th century, when railway ties were first set on fire in the furnace to provide power.

Steel and fire...

- Non-combustible material, does not participate in the heat load (RF1).

- Very rigid and resistant material:
  - Little material for great resistance.
  - Section and slender elements
- Very low massivity (volume/area ratio).

- Highly sensitive to instability phenomena (aggravated in a "fire" situation).



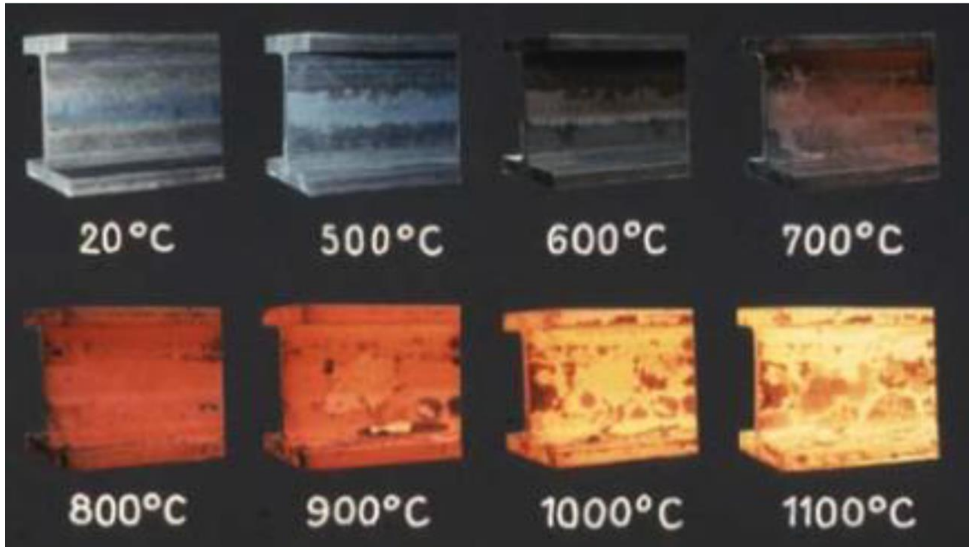
Steel and fire...

SIA 263 Standards

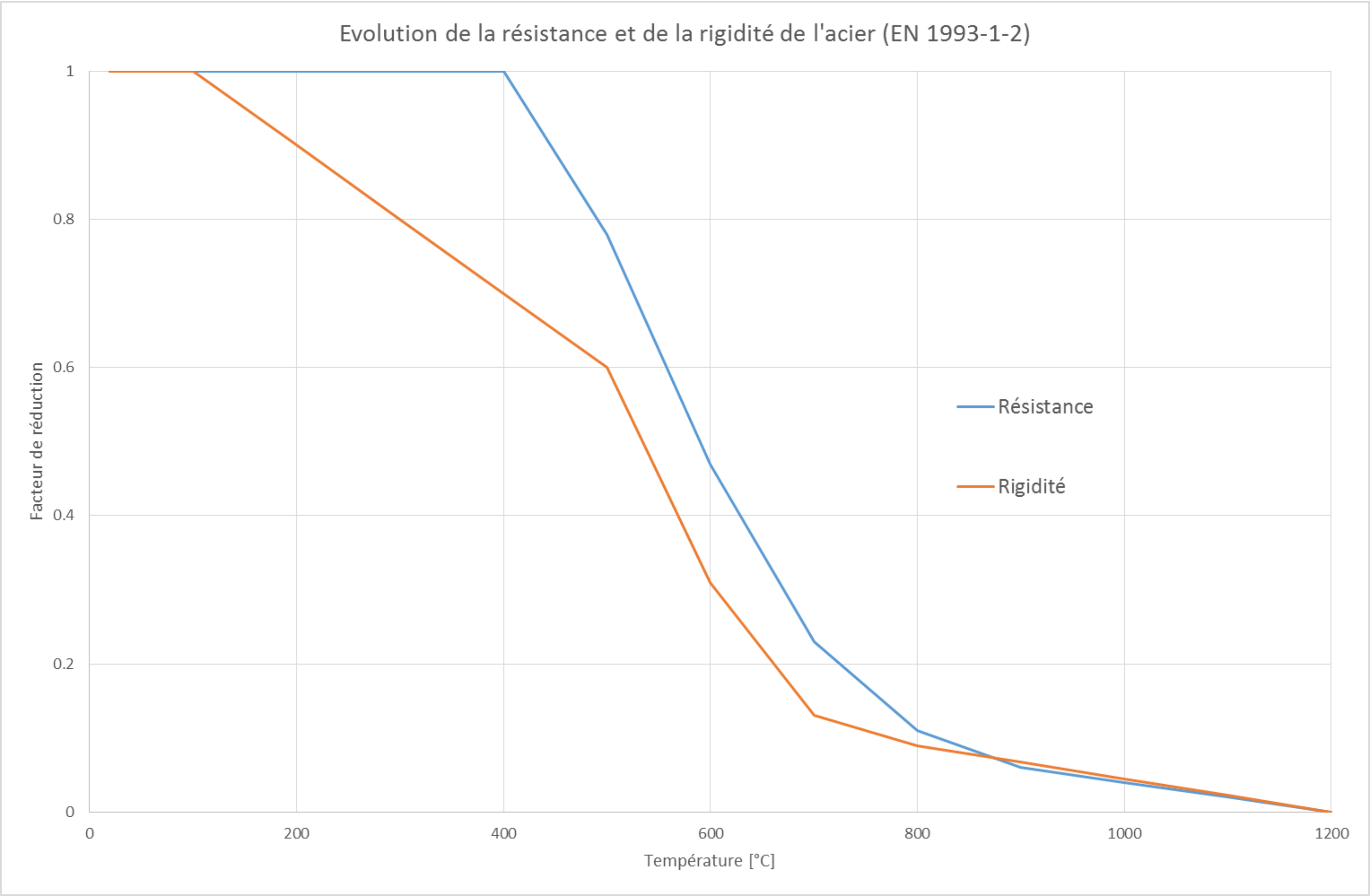
For thermal and mechanical properties, the resistance factor is $\boldsymbol{\gamma_{m,fi}} = \mathbf{1.0}$

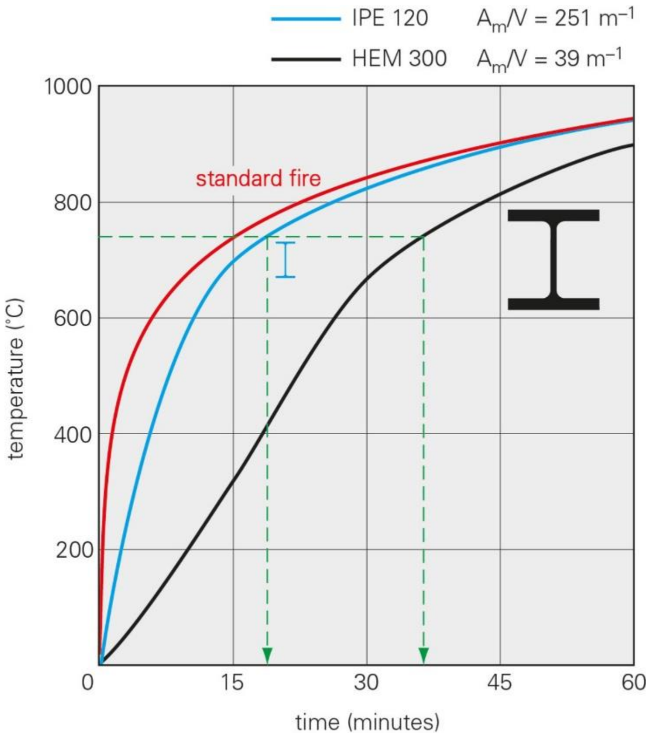
The simplified thermal properties of steel for fire design are as follows:

- Thermal expansion $\Delta_L/L = 14 \cdot 10^{-6}(\theta - 20)$ θ en °C
- Specific Heat $c_a = 600\ J/(kgK)$
- Thermal conductivity $\lambda_a = 45\ W/(mK)$
- Density $\rho_a = 7'850\ kg/m^3$



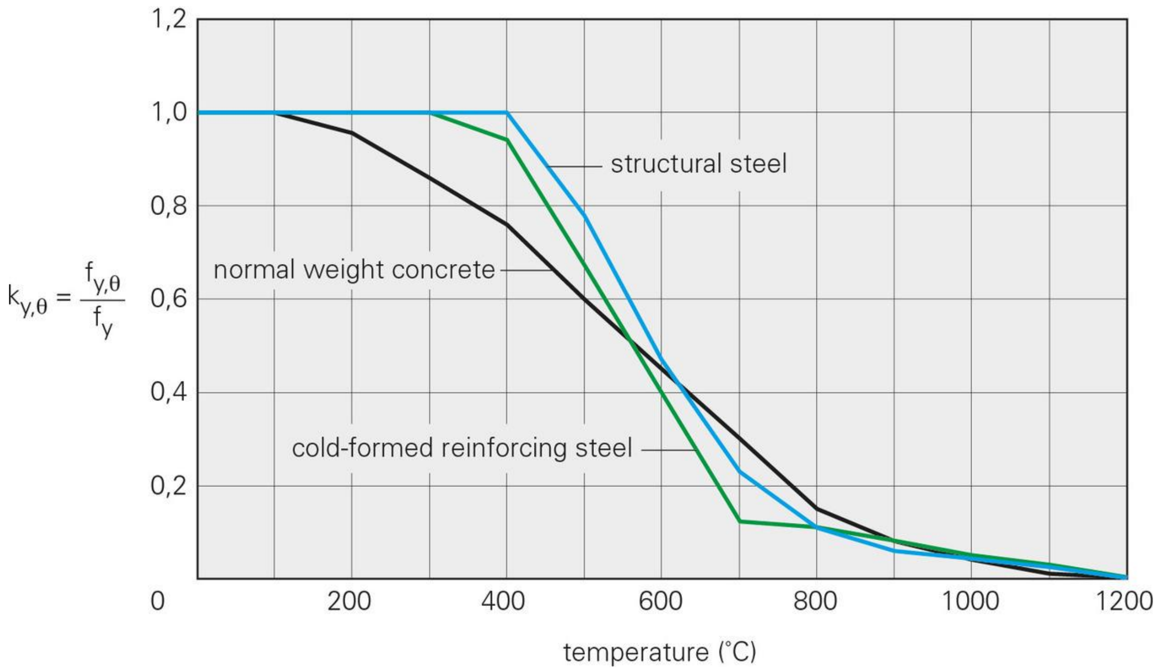
Steel and fire...

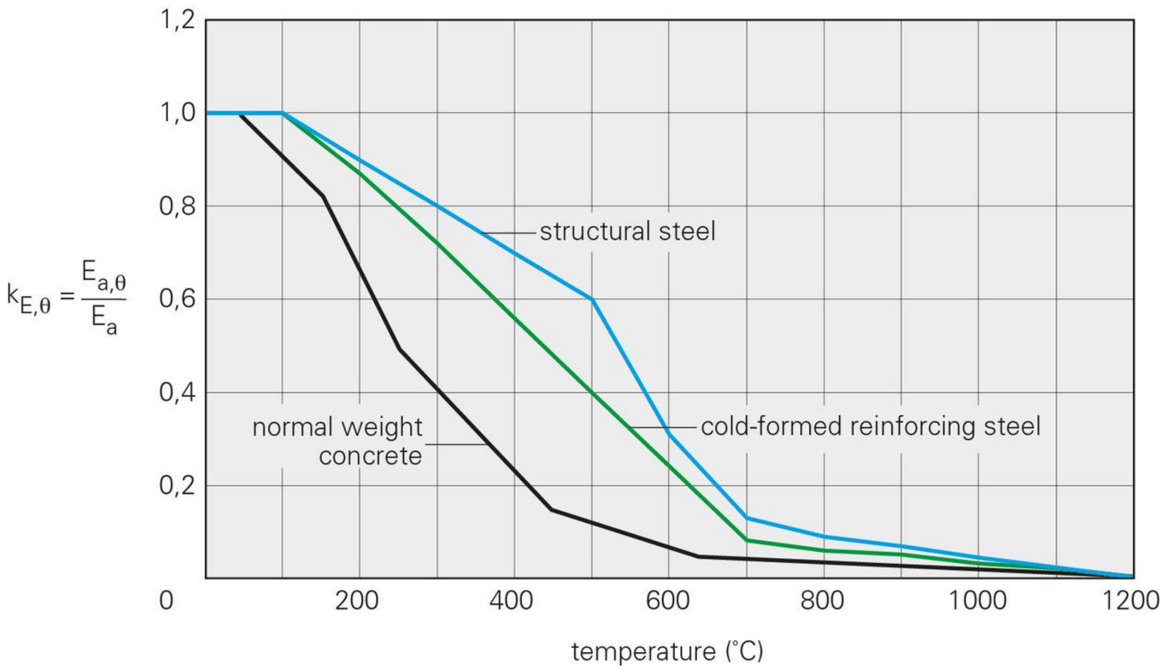




Steel and fire...

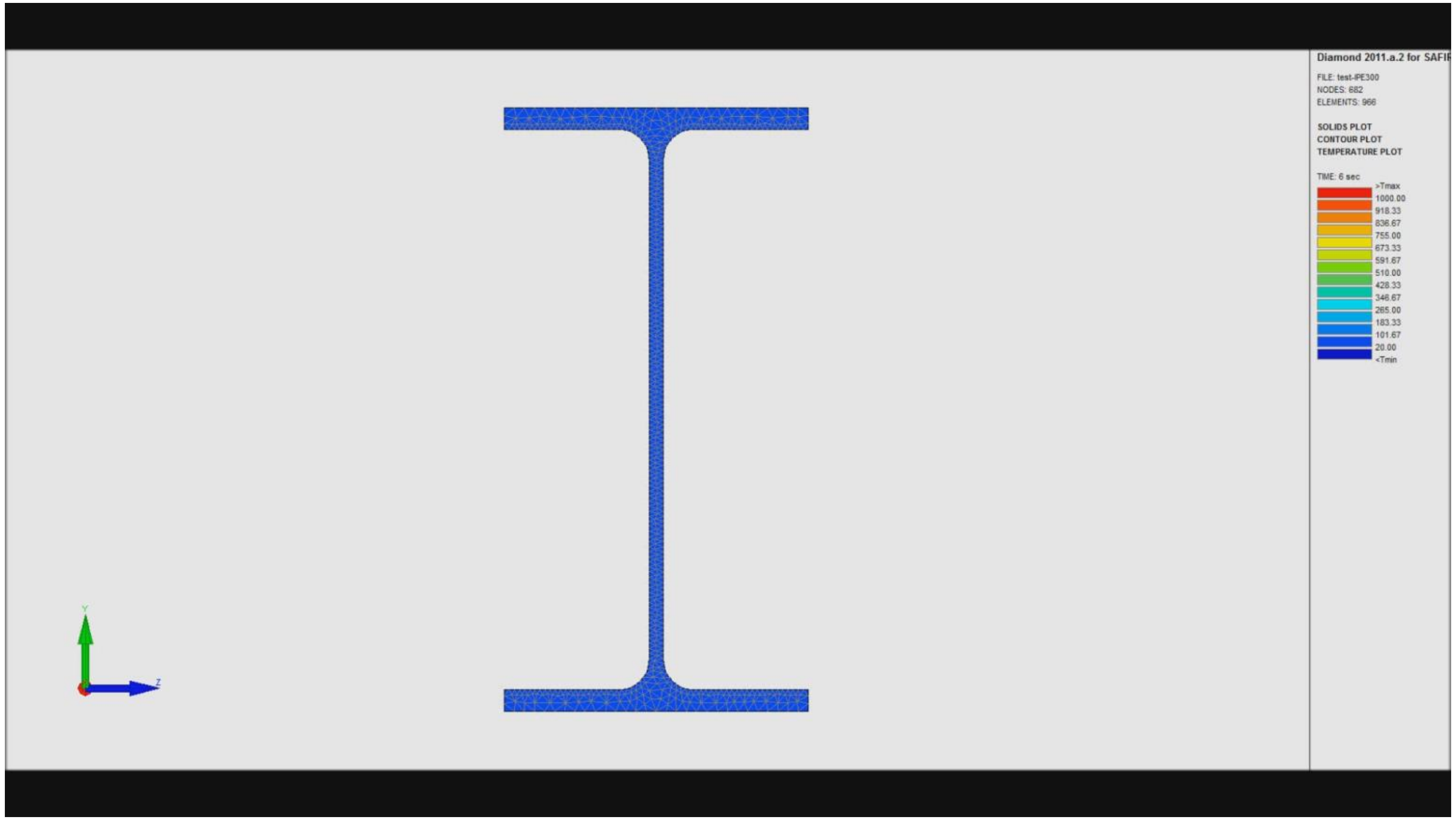
Comparison with other building materials





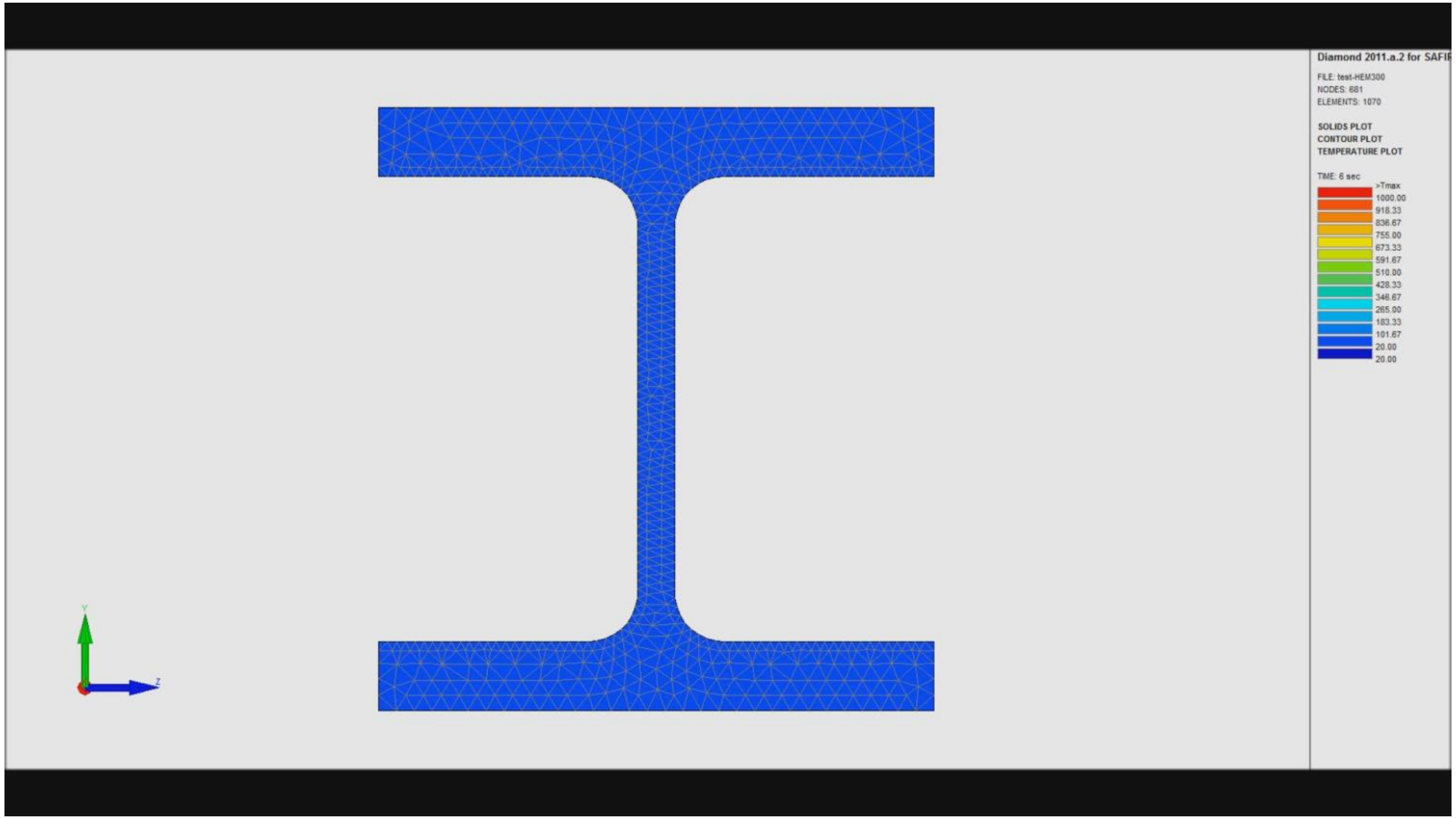
Steel and fire...

- Low massivity: rapid heating of sections under widespread fire and loss of mechanical properties
- Example of IPE 300 column exposed to ISO fire



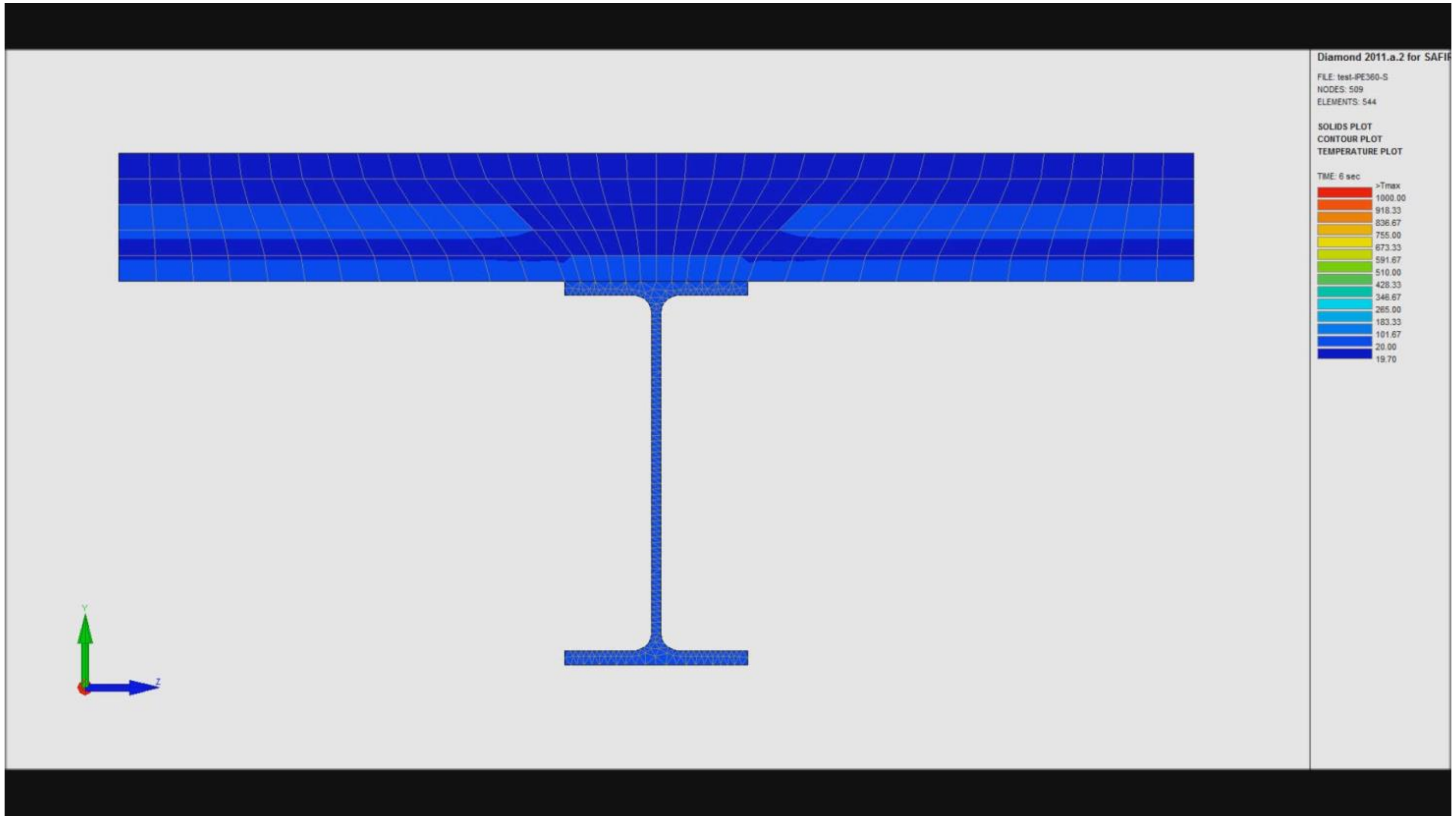
Steel and fire...

- Example HEM 300 column subjected to ISO fire



Steel and fire...

- Example IPE 360 beam with mixed floor



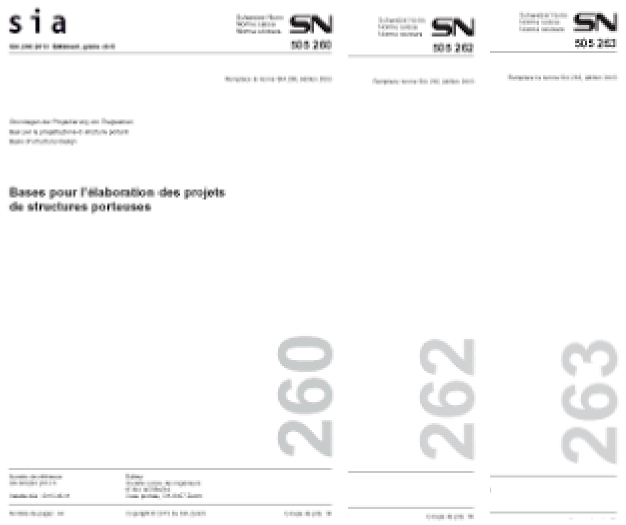
Design in a "fire" situation

Basis of design in the event of fire

SIA Standards

The SIA standards devote several paragraphs to the problem of fire.

- SIA 260, § 3.3.6
- SIA 261, § 15
- SIA 261/1, § 2 (reference to EC1, Part 1-2)
- SIA 262, § 4.3.10
- SIA 263, § 4.8
- …



- Numerous references to the clauses and methods of the Eurocodes are present.

Basis of design in the event of fire

SIA 260 and 263 allow for the verification of structural safety for fire as an accidental action in the form of

- $E_{d,fi} \leq R_{d,fi,\Theta}$ with $\gamma_{M,fi} = 1.0$

- The design value of the Ed,fi load is determined according to SIA 260 (4.4.3.5)
- $E_{d,fi} = E\{G_k, A_d, \psi_{21} \cdot Q_{ki}\}$

- G_k Characteristic value for quasi-permanent actions
- ψ_{21} reduction coefficient for quasi-permanent actions
- Q_{ki} Characteristic value of a variable share
- A_d Design value of the accidental fire action, including stresses due to deformations

Basis of design in the event of fire

Reduction factor for SIA 260 buildings, Appendix A

Actions	ψ_0 (rares)	ψ_1 (fréquentes)	ψ_2 (quasi permanentes)
Charges utiles dans les bâtiments			
– Catégorie A Locaux habitables	0,7	0,5	0,3
– Catégorie B Locaux administratifs	0,7	0,5	0,3
– Catégorie C Locaux de réunion	0,7	0,7	0,6
– Catégorie D Locaux de vente	0,7	0,7	0,6
– Catégorie E Entrepôts	1,0	0,9	0,8
Charges dues au trafic dans les bâtiments			
– Catégorie F Véhicules en dessous de 30 kN	0,7	0,7	0,6
– Catégorie G Véhicules de 30 à 160 kN	0,7	0,5	0,3
– Catégorie H Toits	0	0	0
Charges de neige	$1 - 60/h$ [1)]	$1 - 250/h$ [1)]	$1 - 1000/h$ [1)]
Forces dues au vent	0,6	0,5	0
Effets de la température	0,6	0,5	0
Actions du sol de fondation			
– Poussée des terres	0,7	0,7	0,7
– Pression hydraulique	0,7	0,7	0,7

[1)] Valeurs non négatives, altitude h en m.

Basis for fire design

A few remarks

At the level of the E_d solicitation, the situation is much more favourable than the "sustainable" ultimate limit state (ULS).
Dead loads play a more important relative role than cold loads.
No reduction in the load due to combustion, nor to the melting of the snow.
No "industrial operation" type action (overhead crane).
No simultaneous occurrence with other accidental actions (shock or earthquake).

Dimensioning according to SN EN 1993-1-2

In the nomogram, the calculated load rate of a construction part is given by:

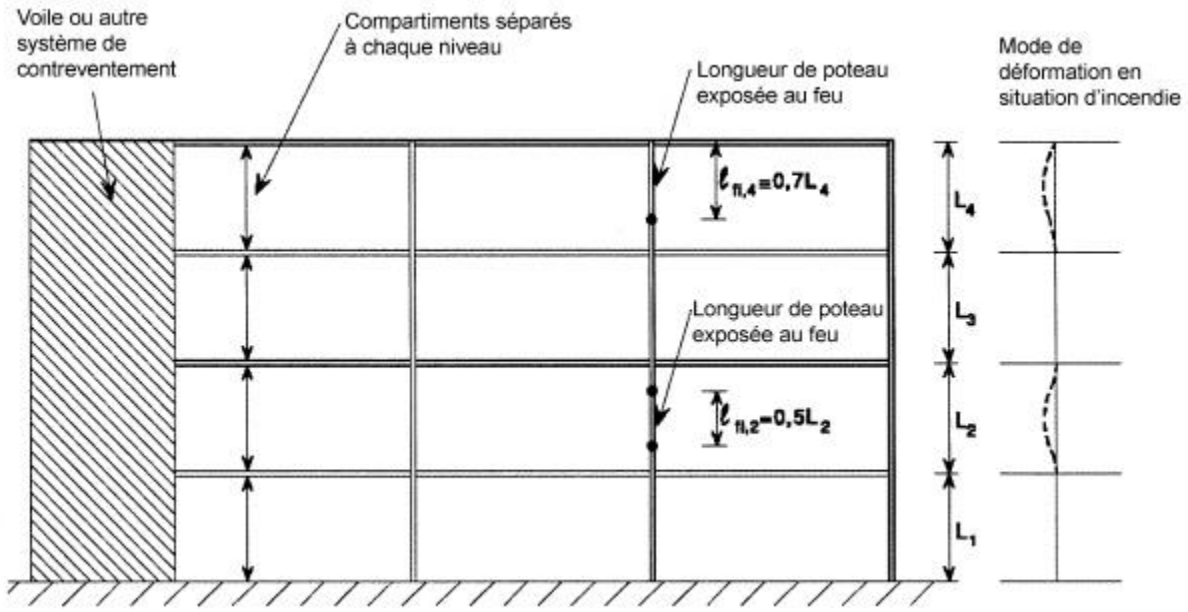
$$\mu_{fi,t} = E_{d,fi}/R_{d,fi,t=0}$$

- $E_{d,fi}$ Calculation value of the load in the event of fire
- $R_{d,fi,t=0}$ Value of ultimate resistance at the start of the fire, at t = 0, at room temperature Θ = 20°C, with $\gamma_M = \gamma_{M,fi} = 1.0$

Basis for fire design

Recessing of columns in the event of a fire

- In a "fire" situation, it is possible to reduce the buckling length of the columns. Indeed, as the fire is generally confined to a single floor, it is permissible to reduce the buckling length.



- CAUTION to be able to use these buckling length reductions, the columns must be continuous or with a rigid or semi-rigid connection.

Simplified calculations – standard concept

- Based on the use of ISO curve as a heat source
- Results from laboratory tests
- Characterization of elements (R30, R60, EI30, EI60)
- Tables available for common elements available in standards and tables (e.g. SIA 264 – EN 1994-1-2 or SZS C1:12 table) or supplied by manufacturers (prefabricated columns, mixed or not)
- Simplified calculation methods (Nomogram)
- Results very often on the safety side, but penalizing from an economic point of view
- Interesting solutions: mixed elements

Example: tabulated values (EN 1994-1-2)

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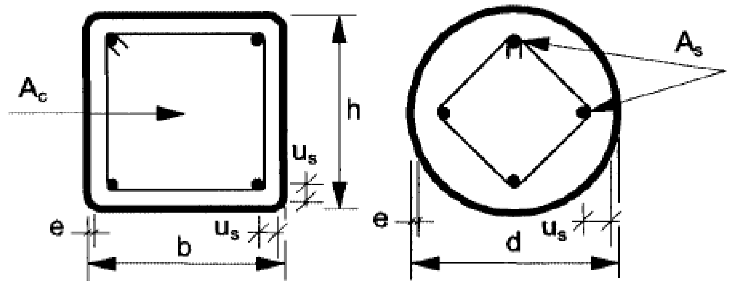
Tableau 4.7 — Dimensions transversales minimales, pourcentage minimal d'armatures et distance d'axe minimale des armatures à la paroi interne, pour des poteaux mixtes en profils creux remplis de béton



Profil en acier : $(b/e) \geq 25$ ou $(d/e) \geq 25$

		Résistance au feu normalisé				
		R30	R60	R90	R120	R180
1	Dimensions minimales de la section pour un niveau de chargement $\eta_{fi,t} \leq$ **0,28**					
1.1	Dimensions minimales *h* et *b* ou diamètre *d* mini [mm]	160	200	220	260	400
1.2	Pourcentage minimal d'armatures $A_s/(A_c + A_s)$ en (%)	0	1,5	3,0	6,0	6,0
1.3	Distance d'axe minimale des armatures u_s [mm]	—	30	40	50	60
2	Dimensions minimales de la section pour un niveau de chargement $\eta_{fi,t} \leq$ **0,47**					
2.1	Dimensions minimales *h* et *b* ou diamètre *d* mini [mm]	260	260	400	450	500
2.2	Pourcentage minimal d'armatures $A_s/(A_c + A_s)$ en (%)	0	3,0	6,0	6,0	6,0
2.3	Distance d'axe minimale des armatures u_s [mm]	—	30	40	50	60
3	Dimensions minimales de la section pour un niveau de chargement $\eta_{fi,t} \leq$ **0,66**					
3.1	Dimensions minimales *h* et *b* ou diamètre *d* mini [mm]	260	450	550	—	—
3.2	Pourcentage minimal d'armatures $A_s/(A_c + A_s)$ en (%)	3,0	6,0	6,0	—	—
3.3	Distance d'axe minimale des armatures u_s [mm]	25	30	40	—	—

Thermal actions

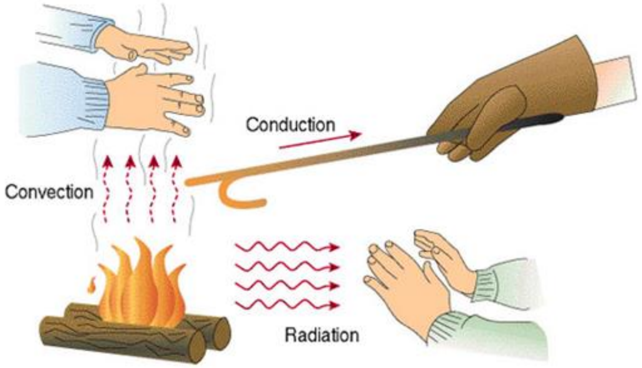
- "Thermal action" is defined as the thermal environment generated by fire
- Time-temperature relationship
- Heat Flow Affecting Structure
- Peculiarity of thermal action: indirect effects
  - These are the effects of actions generated in the elements when their thermal expansion is prevented
  - They are of different natures ("internal")

- According to Eurocode 1, indirect effects are to be taken into account unless:
  - They considered a priori as negligible or favorable (to the engineer's judgment).
  - They are taken into account indirectly (and safely) in the choice of supports and boundary conditions of the structure studied (element, substructure, entire structure). This is the case for the simplified method according to SN EN 1993-1-2.

Thermal action

- The net heat flux that impacts the metal structure is defined by the formula below, which takes into account convective and radiant heat transfer.

$$h_{net} = h_{net,c} + h_{net,r} = \alpha_c\left(\theta_g - \theta_m\right) + \varepsilon_m \sigma(\theta_g^4 - \theta_m^4)$$



- α_c convective heat transfer coefficient (25 $W/(m^2K)$ for exposure according to the standard curve
- θ_g temperature of gases in fire around element [K]
- θ_m surface temperature of the metal element [K]
- ε_m Surface emissivity of the metal element (steel = 0.7)
- σ Constant of Stephan Boltzmann (5.67 10^{-8} W/m^2K)

Basis of design in the event of fire

Nomogram according to EN 1993-1-2:2005

- Uses the concept of the critical temperature θ_{cr}, i.e. that of the ruin of the steel structure, as a function of its utilization rate μ_0.
- Based on ISO 834 "Standard" (EN 1363-1) temperature curve.
- Valid for the following structures:
    - Tensile elements in tension
    - Iso and hyperstatic beams in bending
    - Column subject exclusively to axial load
- For all steel classes according to EN 10025 (S235, S275, S355, S 420, S460).
- Valid for profile classes 1 to 3 with $A_m/V>10m^{-1}$, for class 4 the standard critical temperature θ_{cr} = 350 °C.
- Does not take into account the membrane effect.
- Please note that the method is not valid for spill-sensitive elements or those subject to a combination of loads.

Nomogram according to EN 1993-1-2:2005

Adaptation coefficients κ_1 and κ_2

- **Adaptation coefficient** κ_1 (temperature distribution in beam section)
  - Exposed to fire on all sides $\kappa_1 = 1.00$
  - Exposed to fire on three sides, unprotected, with concrete slab on the 4th side $\kappa_1 = 0.70$
  - Exposed to fire on three sides, protected, with concrete slab on the 4th side $\kappa_1 = 0.85$

- **Adaptation coefficient** κ_2 (temperature distribution along the length of the beam)
  - Supporting a hyperstatic beam $\kappa_2 = 0.85$
  - In other cases $\kappa_2 = 1.00$

Nomogram according to EN 1993-1-2:2005

Mass factor for uncoated steel members

- The mass factor is the ratio between the surface area of the element subjected to the fire A_m and its volume V.

$$\left[\frac{A_m}{V}\right]_{sh} = k_{sh} \cdot \left[\frac{A_m}{V}\right]$$

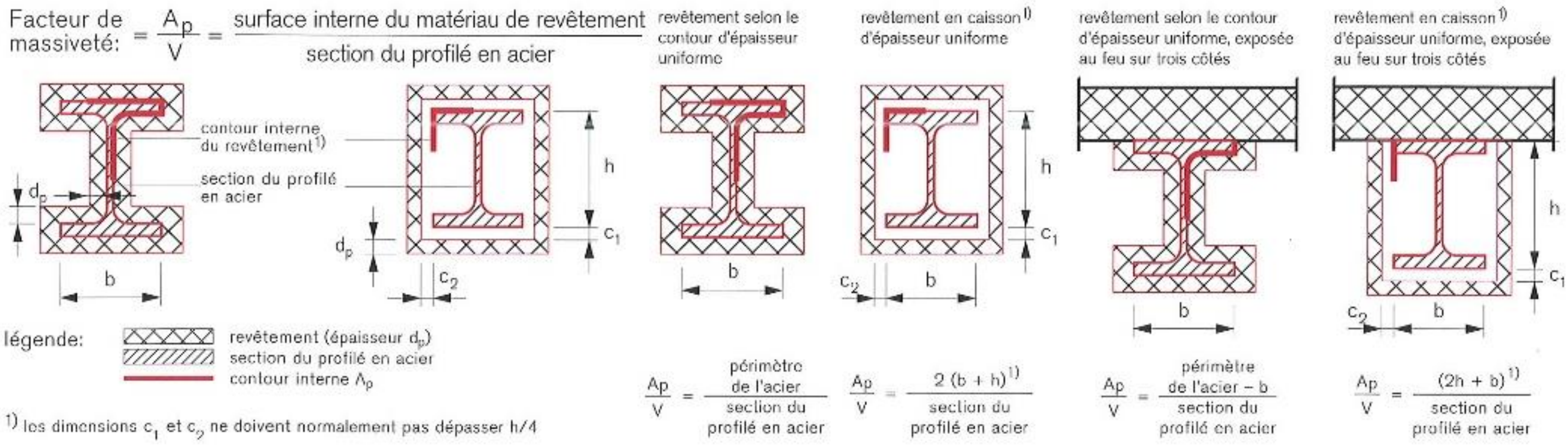
- Depending on the geometry of the profile, the shading effects that are taken into account with the correction factor must be taken into account k_{sh}.
- In the case of a double tee profile, the reduction factor k_{sh} can be reduced by a further 10%.

$$\left[\frac{A_m}{V}\right]_{sh} = 0.9 \cdot \left[\frac{A_m}{V}\right]_b$$

Nomogram according to EN 1993-1-2:2005

Mass factor for coated steel elements

The mass factor for coated profiles is determined according to the diagrams below.



- The mass factors of the individual profiles can be found on the SZS website https://www.szs.ch/fr/protection-incendie-downloads/

Nomogram according to EN 1993-1-2:2005

Coating materials and paint

- For coated steel elements, the A_m/V mass factor is replaced by the thermal mass factor

$$\frac{A_p}{V}\cdot\frac{\lambda_p}{d_p}\cdot\frac{1}{1+0.5\phi} \quad with\ \phi=\frac{c_p\cdot d_p\cdot\rho_p\cdot A_p}{c_a\cdot\rho_a\cdot V}$$

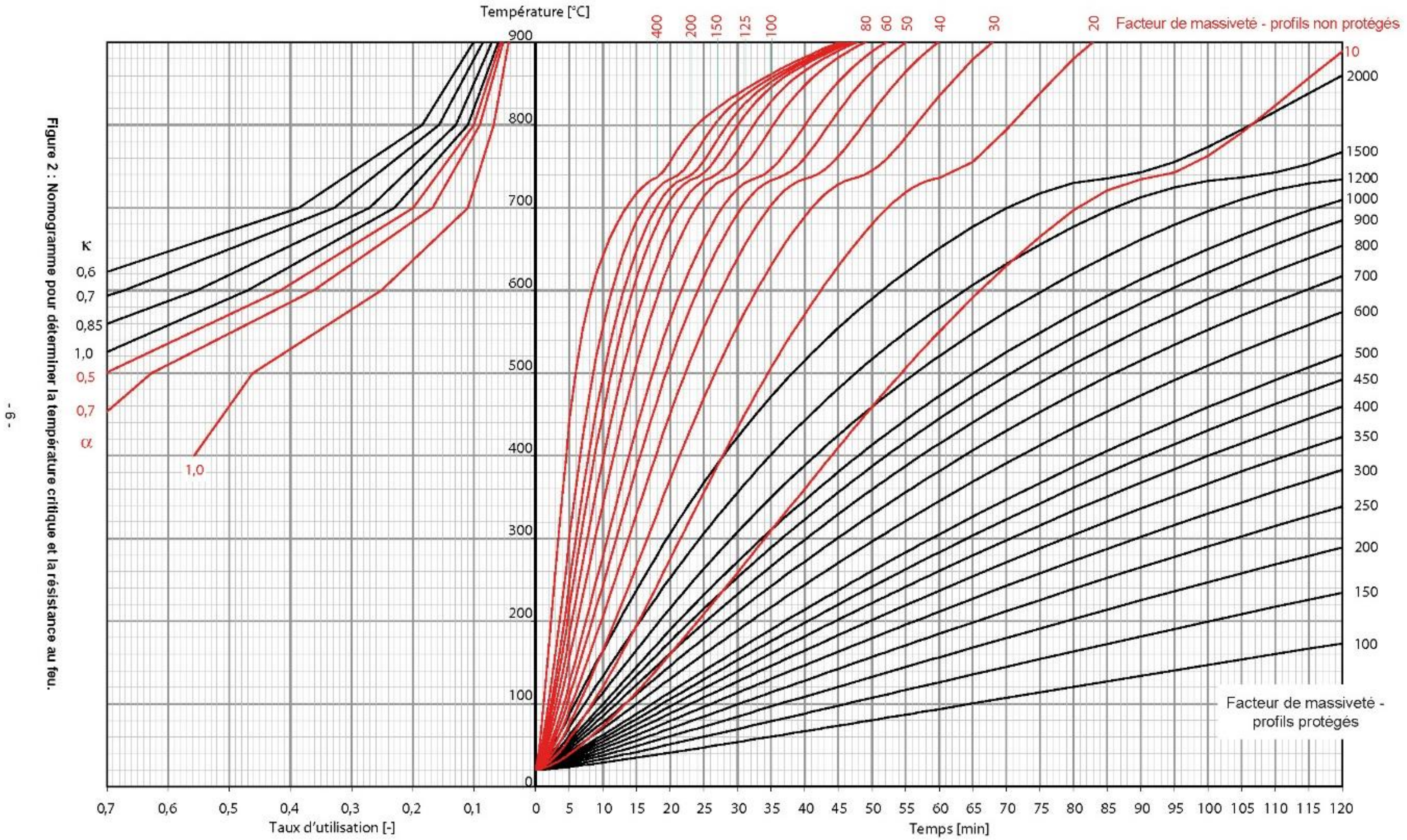
- As a first approximation, we can take ϕ = 0 (this leads to a safe result).
- The coating must be installed in accordance with the supplier's installation instructions to ensure that protection remains in place for the expected time.
- For a first calculation, we can take the values in Table 1.
- It is necessary to check that the characteristics of the product installed are equivalent to those used in the calculation.

Matériau	Masse volumique ρ_p [kg/m^3]	Teneur en eau p [%]	Conductibilité thermique λ_p [W/(m·K)]	Chaleur spécifique c_p [J/(kg·K)]
Crépis projetés				
- fibres minérales	300	1	0.12	1200
- vermiculite / perlite	350	15	0.12	1200
Crépis projetés à haute densité				
- vermiculite ou perlite et ciment	550	15	0.12	1100
- vermiculite ou perlite et anhydrite	650	15	0.12	1100
Plaques				
- vermiculite ou perlite et ciment	800	15	0.20	1200
- fibres-silicate ou silicate de calcium	600	3	0.15	1200
- fibre de ciment	800	5	0.15	1200
- plaques de plâtres	800	20	0.20	1700
Fibres comprimées				
- plaques de fibres silicate, laine de roche, laine minérale	150	2	0.20	1200
Béton	2300	4	1.60	840
Béton léger	1600	5	0.80	1200
Blocs de béton	2200	8	1.00	1200
Briques creuses	1000	-	0.40	1200
Briques pleines	2000	-	1.20	1200

Table 1

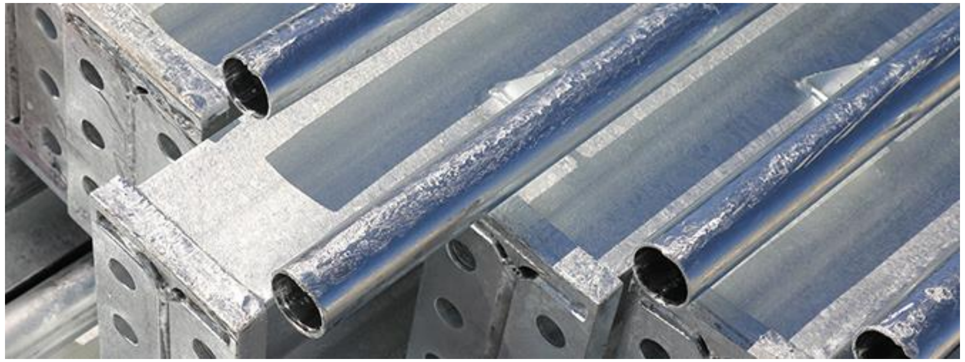
Nomogram according to EN 1993-1-2:2005

- With "standard" ISO curve only.
- For protected or unprotected profiles.



Special case of galvanized steel

- Hot-dip galvanizing has a positive influence on the resistance of metal structures in fire situations.
- Hot-dip galvanized surfaces act on the heat radiation like a partially reflective mirror.
- This effect works as long as the hot-dip galvanizing remains reflective. From a surface temperature slightly above 500°C, the surface of the zinc layer loses its reflective properties and the effect ceases.
- The favourable influence of hot-dip galvanising on the fire resistance of load-bearing elements can be taken into account during the design by halving the emissivity of steel surfaces for surface temperatures up to 500°C in the calculation of the fire behaviour according to SN EN 1993-1-2.

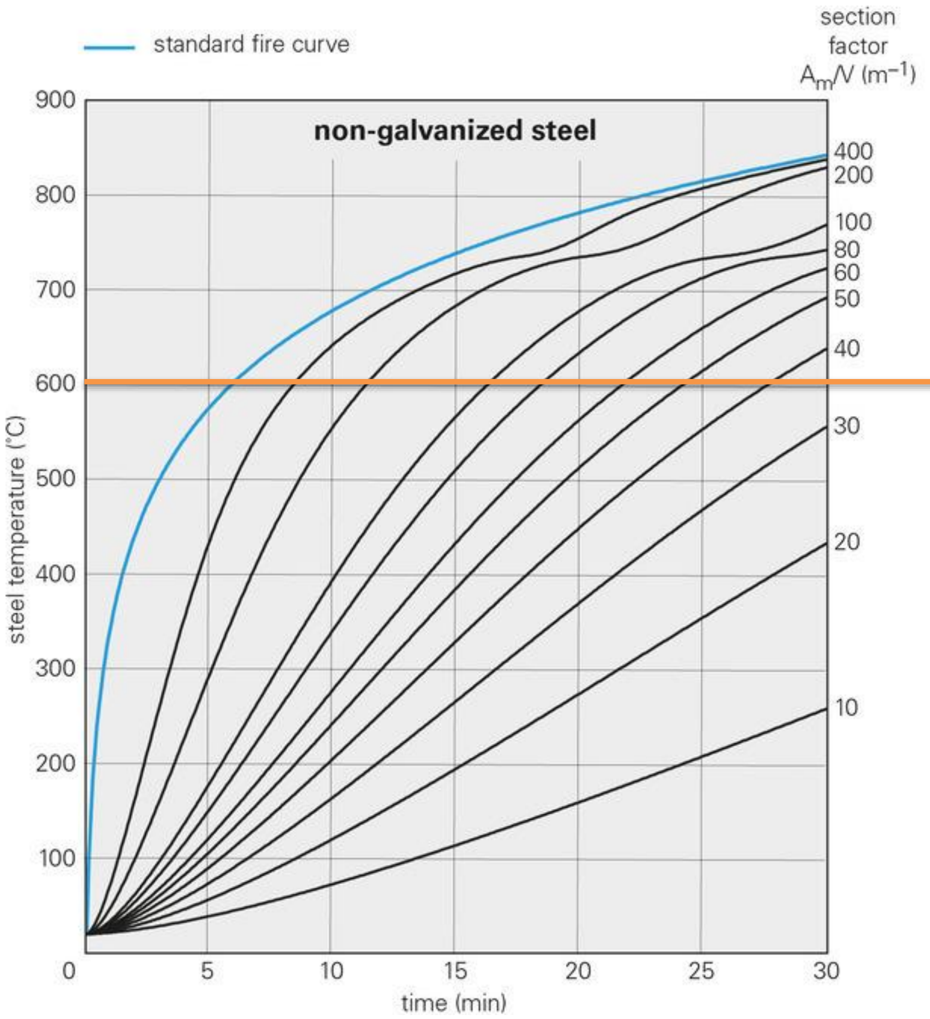


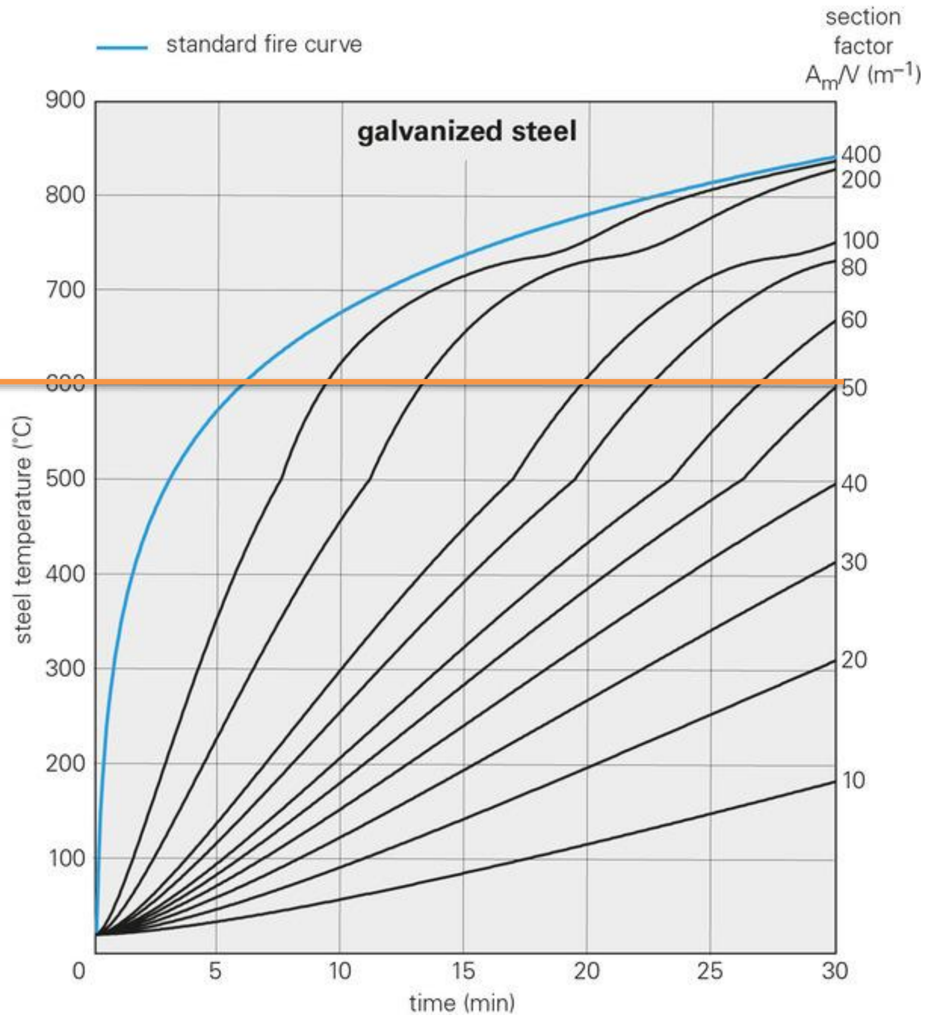
Type d'acier	ε_m (≤ 500°C)	ε_m (> 500°C)
Acier de construction	0.70	
Acier inoxydable	0.40	
Acier de construction galvanisé à chaud selon la norme SN EN ISO 1461 (Catégorie A ou B selon SN EN ISO 14713-2, tableau 1)	0.35	0.70

Special case of galvanized steel

- Hot-dip galvanizing acquires its fire protection properties already during production. Over time, a protective layer (patina) is formed, which changes the visual appearance of the zinc coating.
- The emissivity values are not affected and remain unchanged for the entire service life of the coating.
- As a rule, metal components have a resistance of 15 – 20 minutes under the thermal action of the standard ISO curve.
- In some cases, the strength of the unprotected steel load-bearing element is just insufficient and the favourable effect of hot-dip galvanizing is sufficient to ensure that the R 30 strength is achieved.
- **However, this must always be verified by calculation, e.g. with the help of a nomogram, by a cross-sectional thermal calculation or a 3D analysis, in accordance with Art. 11 or 12 of the AEAI Fire Protection Standard 1-15.**
- For the longer fire resistance times (R 60, R 90), the influence of hot-dip galvanizing is usually minimal.

Special case of galvanized steel





https://www.feuerverzinken.com/anwendungen/bauen/brandschutz

Bibliography and sources

STANDARDS
SIA 260 Basis for the development of supporting structure projects
SIA 261 Actions on load-bearing structures
SIA 263 Steel Construction
SIA 264 Steel-Concrete Composite Construction
SIA 265 Timber Construction

SN EN 1991-1-2 Eurocode 1: Action on structures
Part 1-2: General Actions – Actions on Structures Exposed to Fire
SN EN 1993-1-2 Eurocode 3 – Design of Steel Structures
Part 1-2: General Rules – Calculation of Fire Behaviour
SN EN 1993-1-8 Eurocode 3 – Assemblies
SN EN 1994-1-2 Eurocode 3 – Design of Steel Structures
Part 1-2: General Rules – Calculation of Fire Behaviour

PUBLICATIONS
Structural fire protection – Steeldoc 02/06 – SZS
Design table for composite construction C1/12 – SZS
AEAI – Fire Protection Prescription 2015 www.bsvonline.ch

Bibliography and sources

BOOKS
Fire Design of Steel Structures - Jean-Marc Franssen and Paulo Vila Real -ECCS: 2010
Membrane Action of Composite Structures in Case of Fire - Olivier Vassart and Bin Zhao - ECCS: 2013
Fluid Mechanics Aspects of Fire and Smoke Dynamics in Enclosures – Bart Merci and Tarek Beji – CRC Press: 2016
Principles of Fire Behavior - James-G. Quintiere - CRC Press: 2016
Fire safety and fire resistant design of steel structures for buildings according to Eurocode 3 – A.F. Hamerlinck – Bouven met Staal 2021

WEBSITES
AEAI - Association des Etablissements d'Assurance Incendie www.vkg.ch
SZS : www.szs.ch
ACCESS STEEL guides et exemples de calcul https://www.cticm.com/projets/projet-access-steel/
ECCS *European Convention for Constructional Steelwork (ECCS)* *http://www.steelconstruct.com*
DIFISEK : *Dissemination of Fire Safety Engineering Knowledge* *https://op.europa.eu/en/publication-detail/-/publication/893eb75f-c9d4-445a-8e24-8c708267dfca*
SECURE WITH STEEL *https://sections.arcelormittal.com/about_us/Partnership/Secure_with_Steel/EN*
NIST : *Building and Fire Research Laboratory's Fire Research Division at NIST* *http://www.fire.nist.gov/*

ANY QUESTIONS?

Thank you for your attention