EPFL
RESSLab

Fire Safety & Engineering SA

Fire Protection Engineering

Introductory Course – Part 3

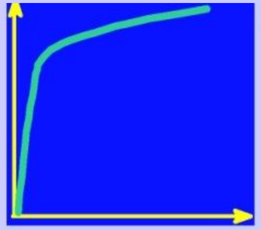
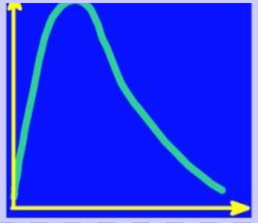
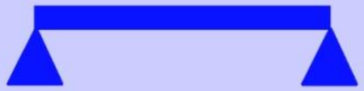
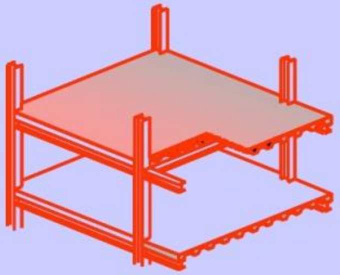
Olivier Burnier, civil engineer HES-UTS
Fire protection expert with federal diploma

Summary

Natural fire

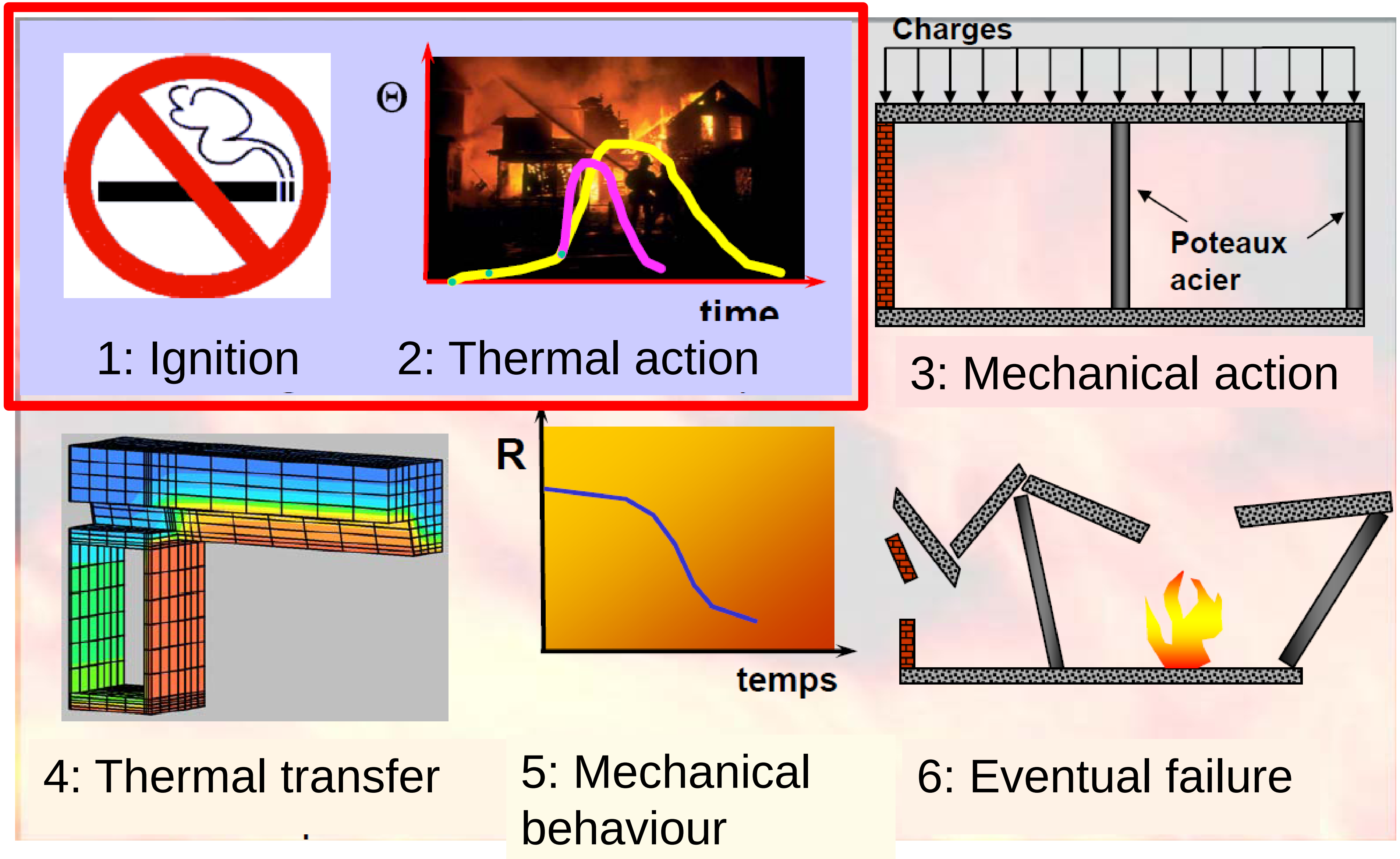
- Thermal action
  - Localized fire
  - Widespread fire
- Mechanical action
- Heat Transfer
- Analysis
- Examples
- Conclusions
- Biography and sources

Fire stability of structures

	descriptif	à objectif
	Conventional fire 	Natural fire 
	classification	Fire behaviour engineering
	Fire behaviour engineering	Fire behaviour engineering

Thermal action

Fire resistance – process



Thermal action

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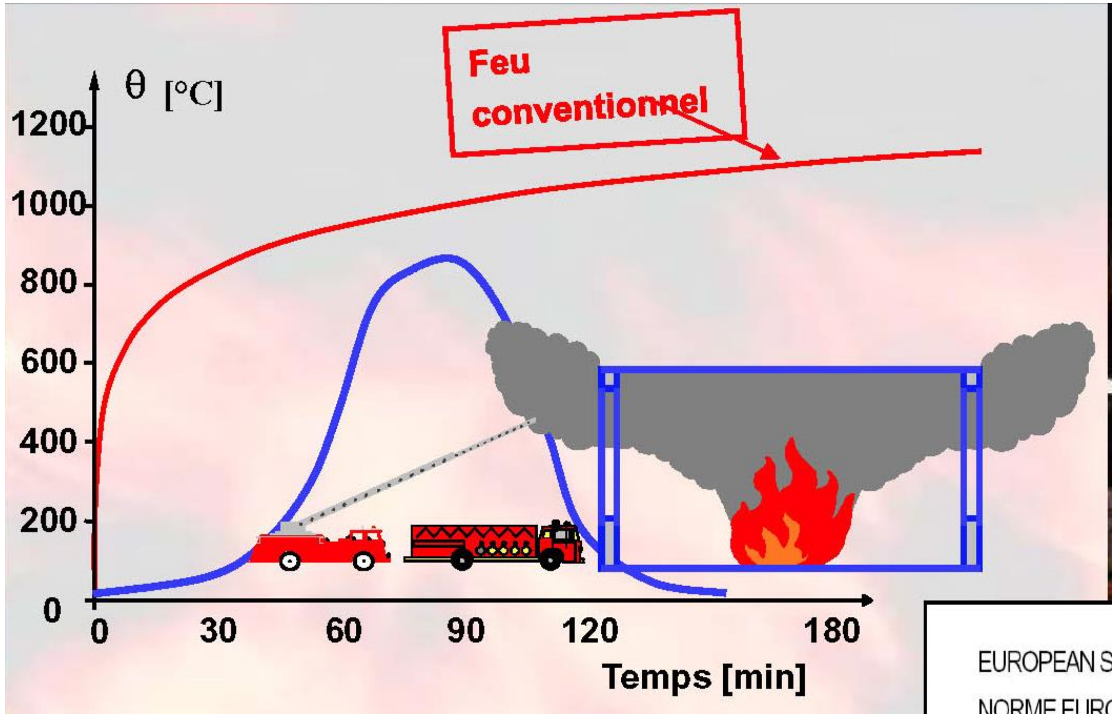
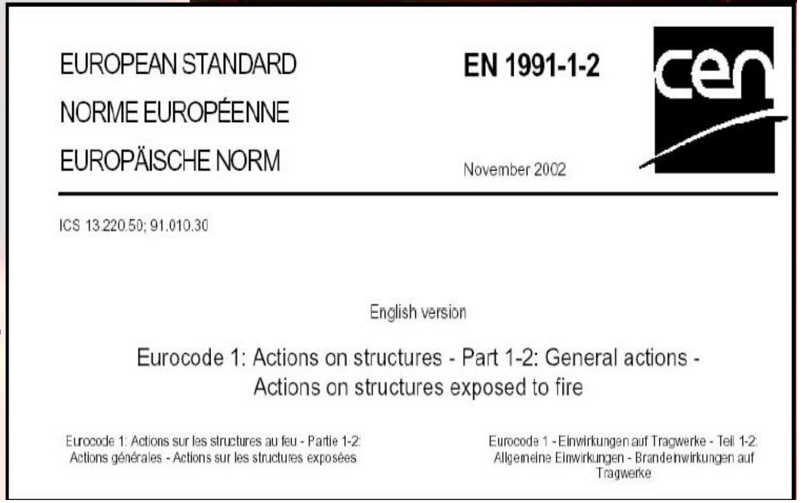
Which thermal action to choose?

- Are all fires the same?
- Are there several "fires" for the calculation?
- How to choose THE representative "fire"?
- Are fires normalized?

→ Mathematical models

Thermal action – natural fire





EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 1991-1-2

November 2002

ICS 13.220.50; 91.010.30

English version

Eurocode 1: Actions on structures - Part 1-2: General actions - Actions on structures exposed to fire

Eurocode 1: Actions sur les structures au feu - Partie 1-2: Actions générales - Actions sur les structures exposées

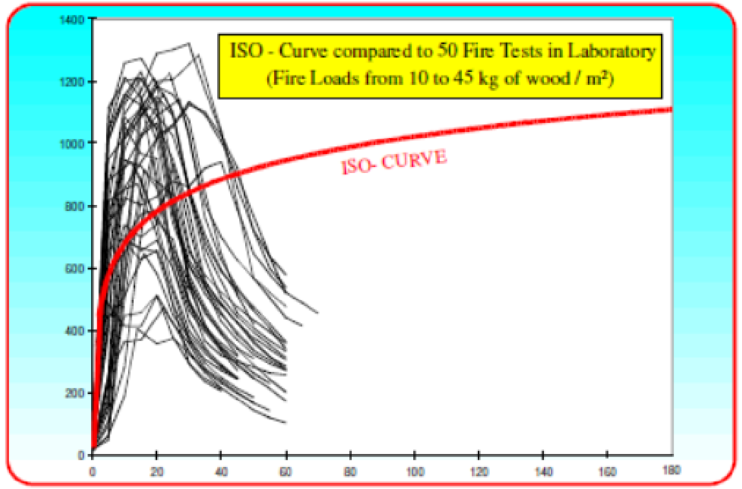
Eurocode 1 - Einwirkungen auf Tragwerke - Teil 1-2: Allgemeine Einwirkungen - Brandeinwirkungen auf Tragwerke

Notions incluses:

- EN 1991-1-2
- Certaines réglementations nationales ont inclus une alternative basée sur le feu naturel

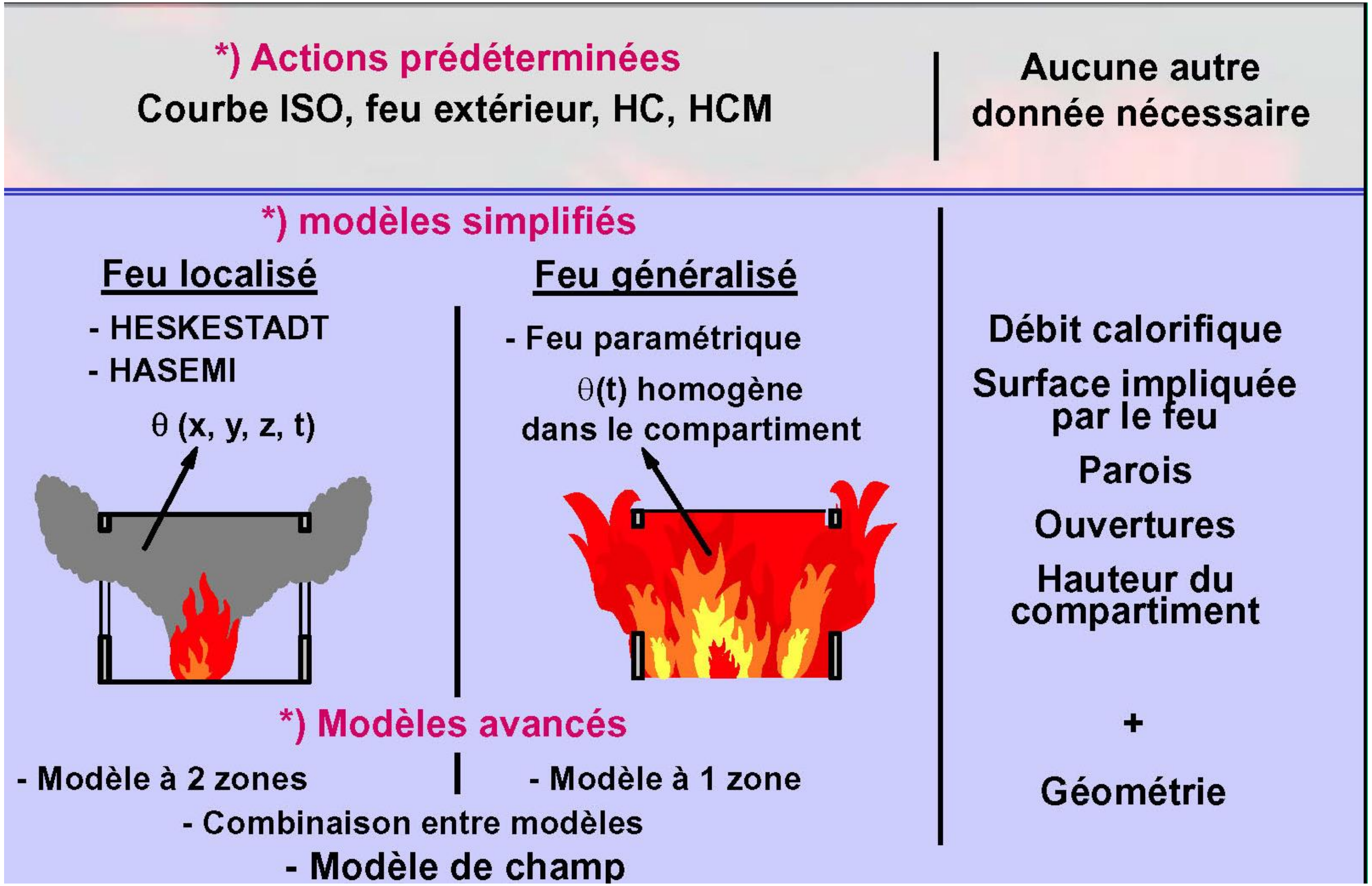
Thermal action – natural fire

- The result of six years of research at the European level.
- Described in SN EN 1991-1-2, § 3.3 and Annex E.
- Has the same probability of ruin as structures calculated "cold" according to Eurocode EN 1990, i.e. 7.23 10-5 during the life of the building.
- Takes into account all the parameters listed in the protective measures.
- Comes as close as possible to the actual conditions of a compartment fire.

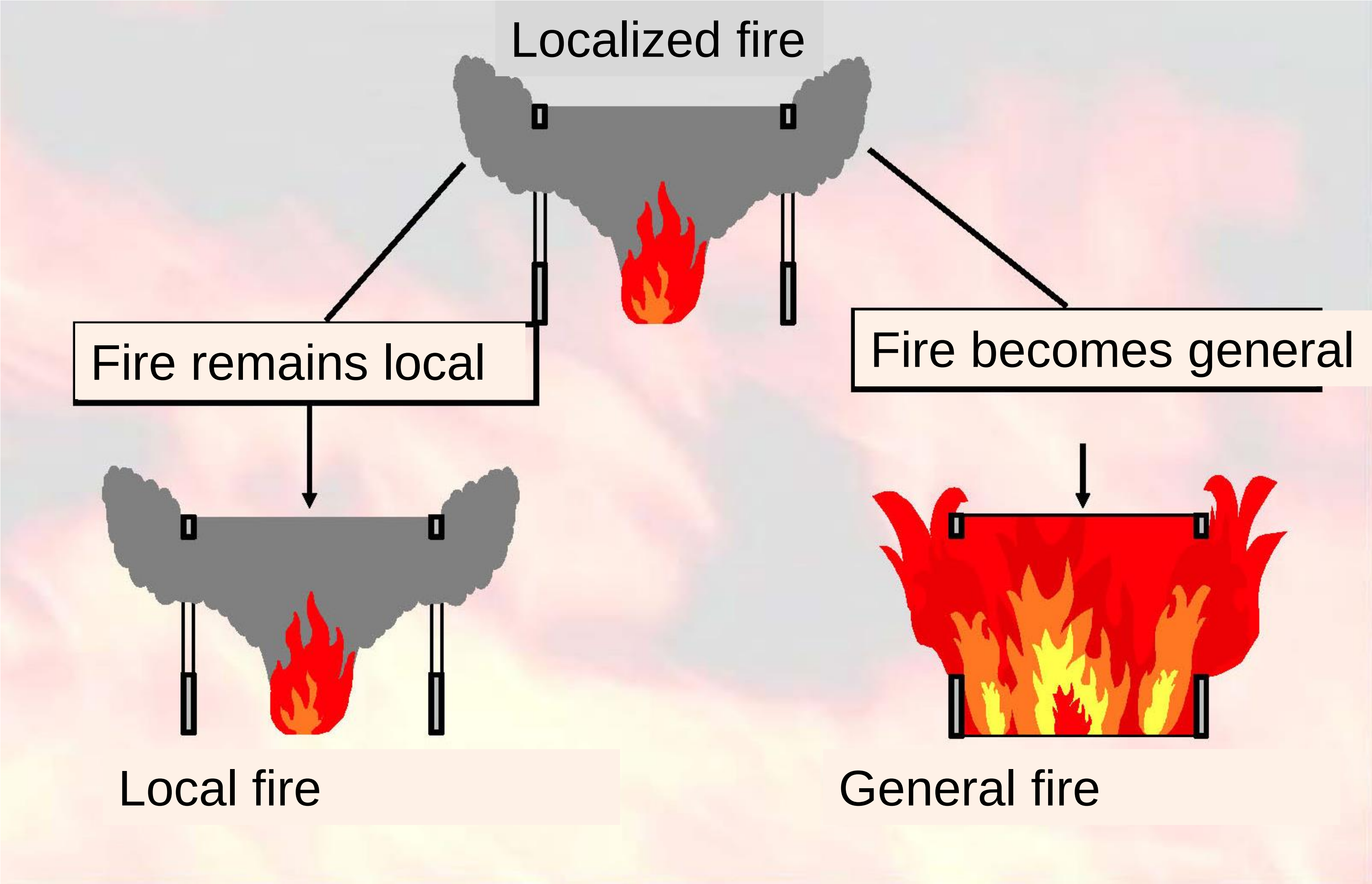


- Is more "economical" for low heat loads and safer for high heat loads.

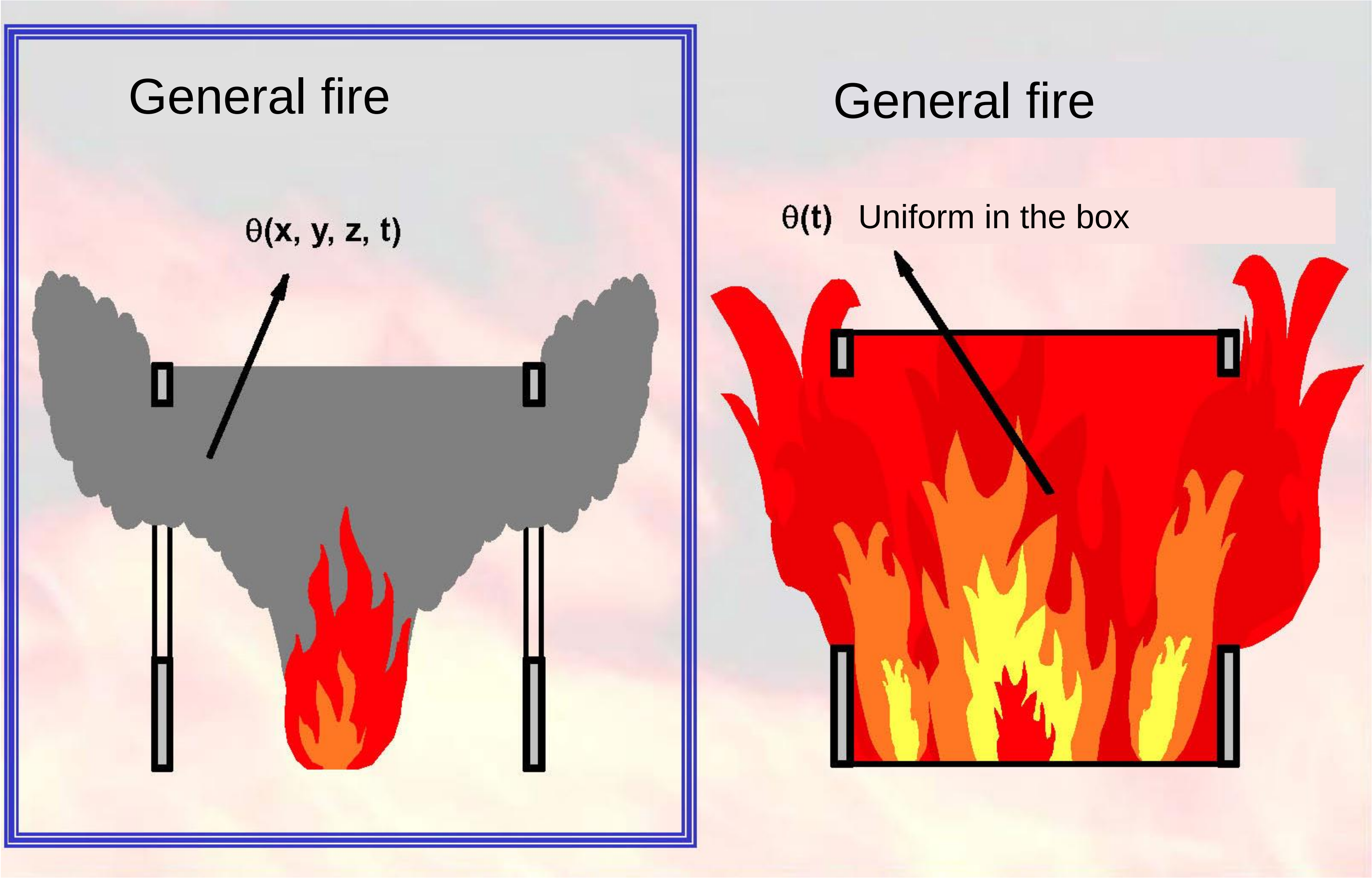
Natural Fire Patterns



Advanced Fire Pattern



Simplified Fire Model – Localized Fire



Localized Fire Testing

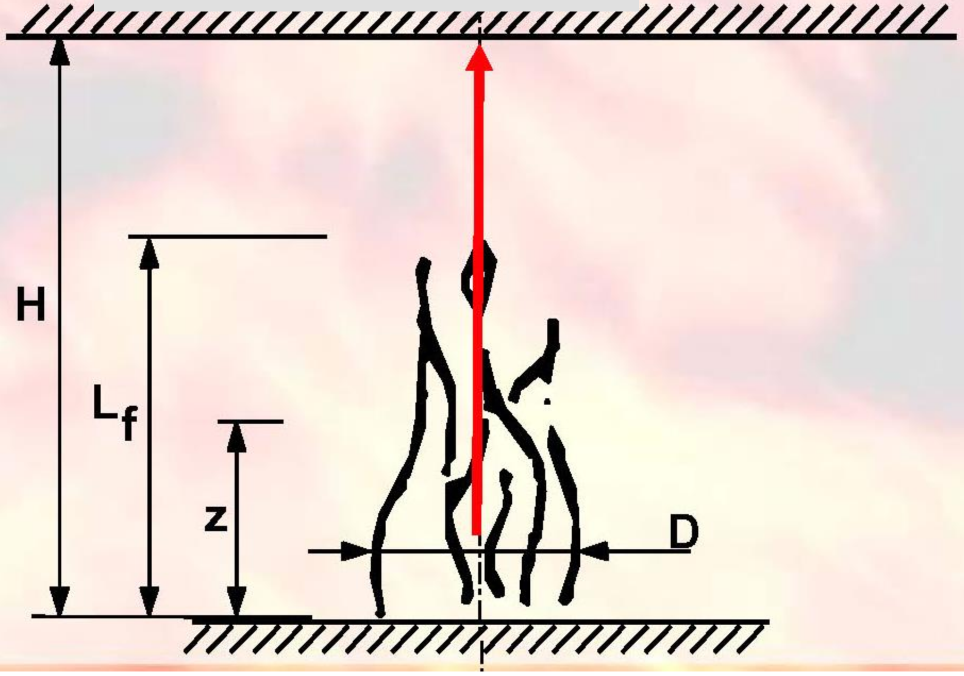
Localized fire – Heskestadt method

- Case of an external fire
- Or if the flames don't touch the ceiling $(L_f < H)$,

Temperature $\Theta_{(z)}$ Along the vertical axis of the flame is given by

$$\Theta_{(z)} = 20 + 0{,}25\, Q_c^{2/3}\, (z - z_0)^{-5/3} \leq 900°C$$

Axis of the flame



Length of the flame L_f :

$$L_f = -1{,}02\, D + 0{,}0148\, Q^{2/5}$$

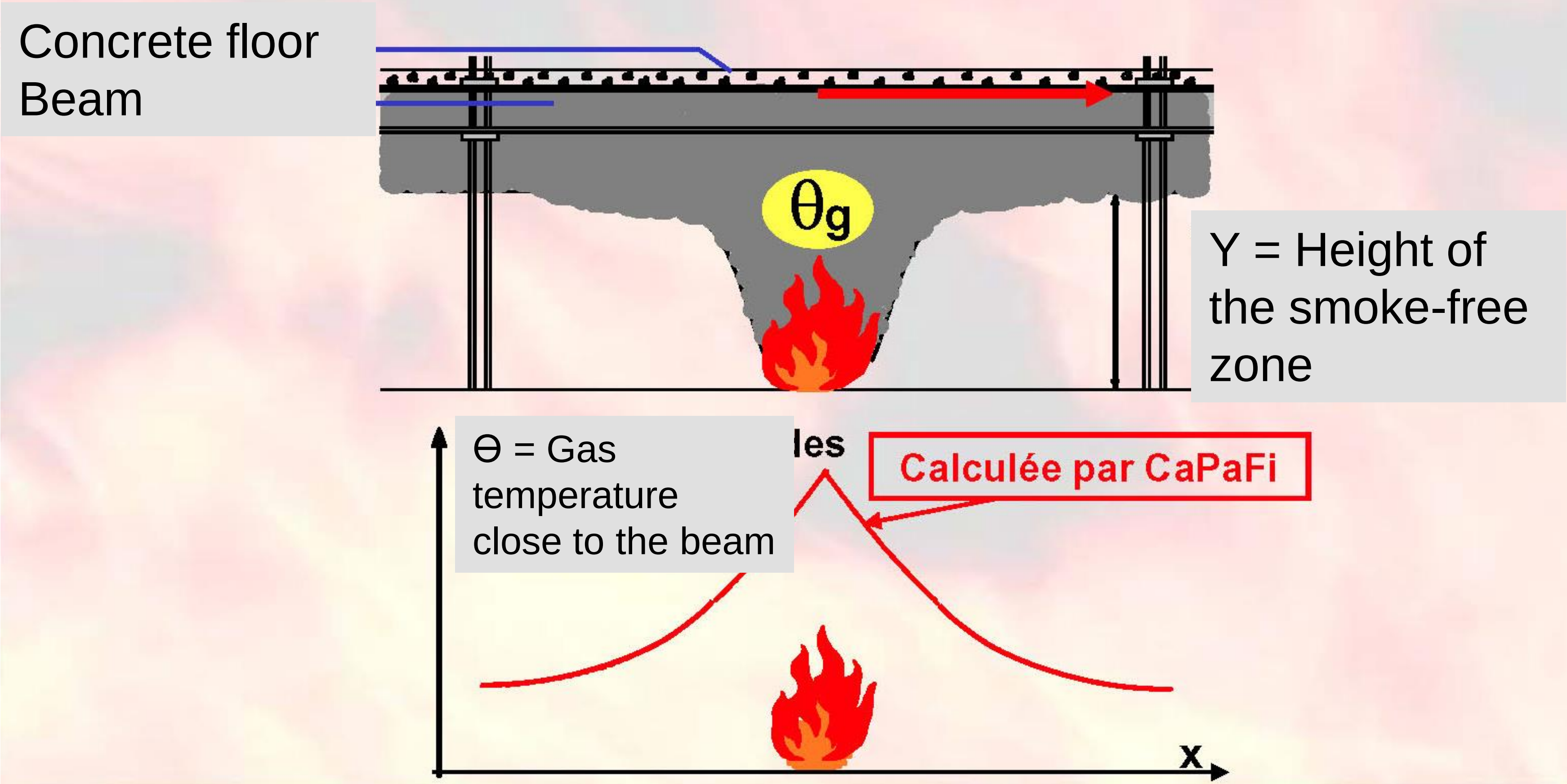
Virtual origin z_0 :

$$z_0 = -1{,}02\, D + 0{,}00524\, Q^{2/5}$$

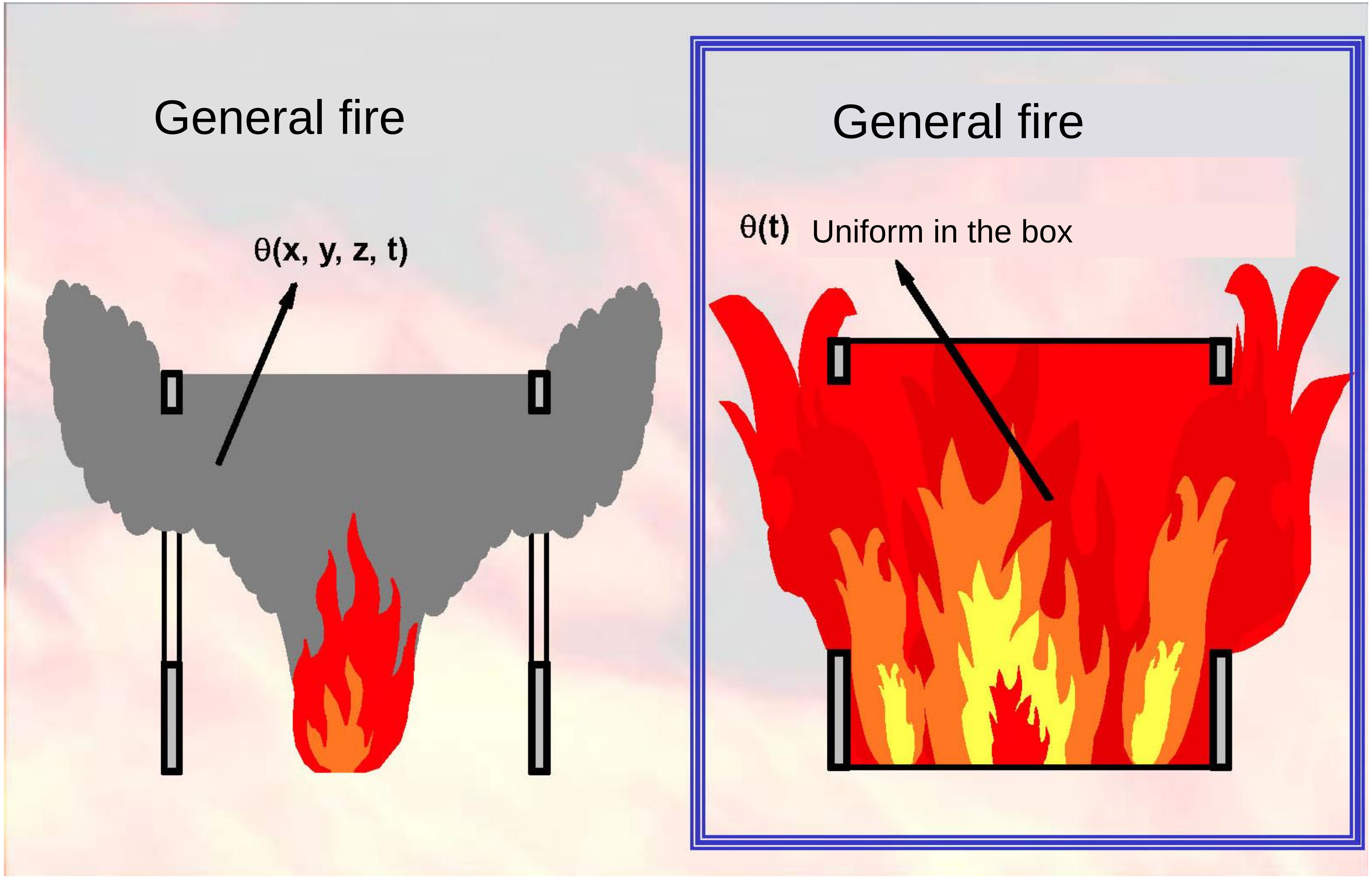
$$Q_c = 0{,}8\, Q$$

Localized fire – Hasemi's method

When the flame touches the ceiling, $(L_f > H)$, the received heat flow per unit of exposed surface is calculated with Hasemi's method

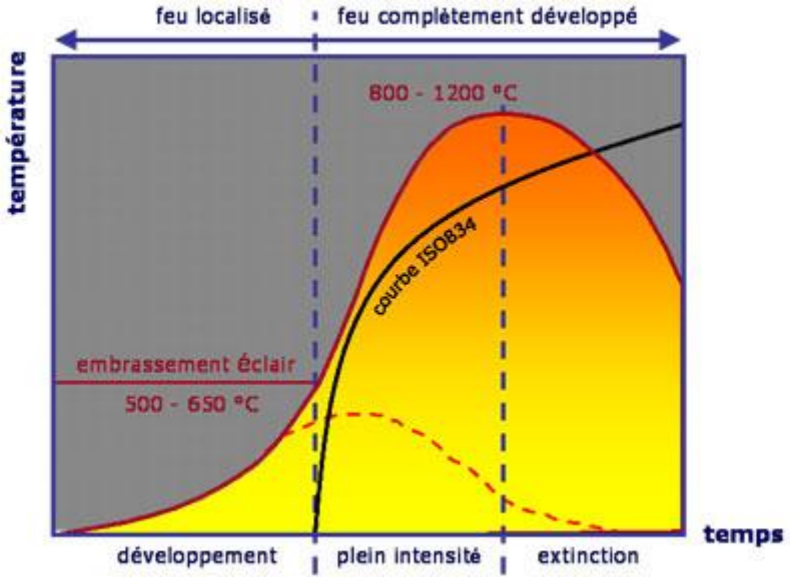


Simplified Fire Model – Widespread Fire



Fire test in a multi-storey office building

Thermal Action - Flashover



Backdraft

Mathematical Model of Ozone

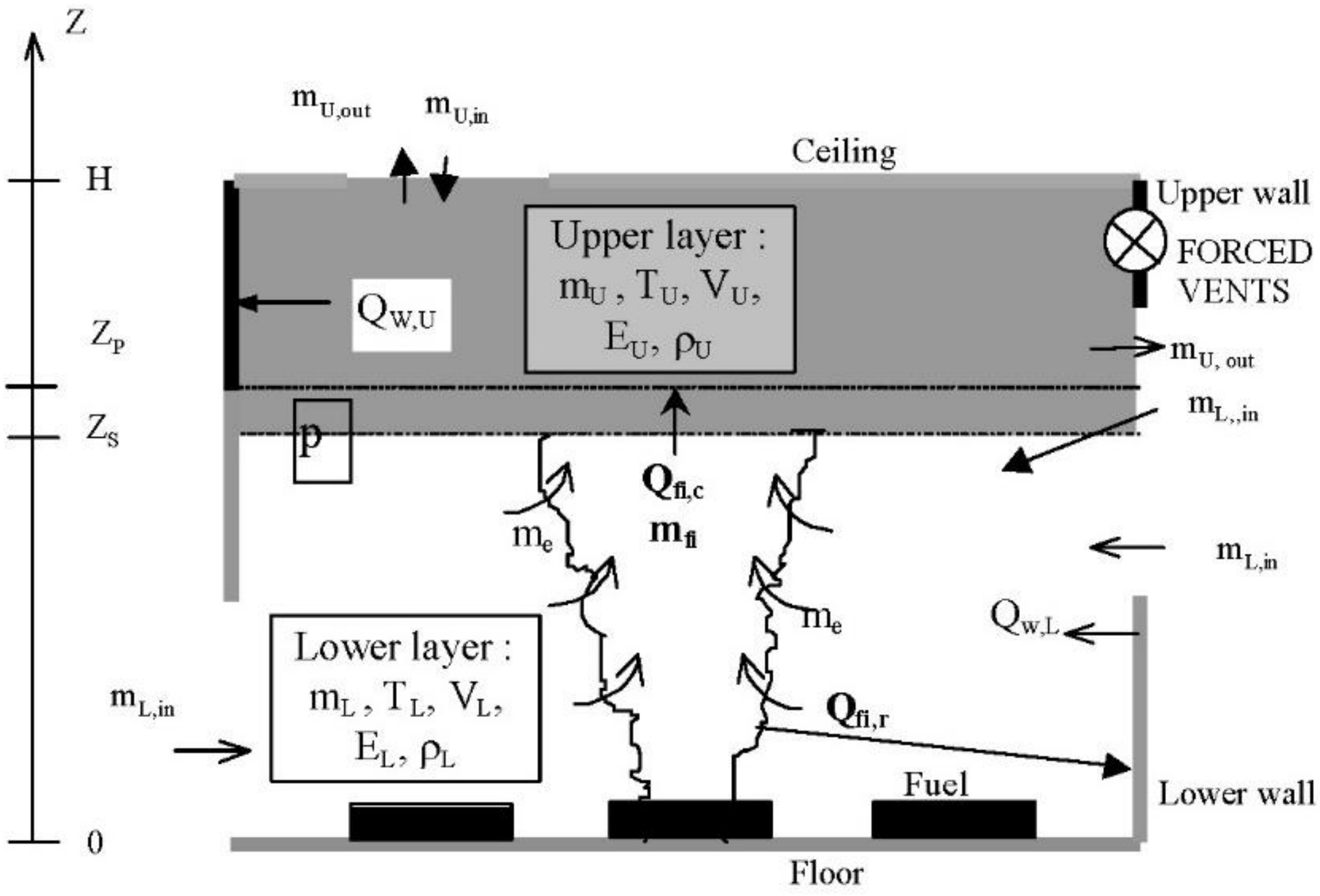


Figure 1 Schematic view of two zone model and associated submodels

Validation of Ozone

- Localized Fire – 39 tests
  - VTT: Hall (8 tests)
  - VTT: local (21 tests)
  - DSTV: local (10 tests)

- Widespread Fire – 71 tests
  - CTICM: local, wood (36 tests)
  - CTICM: local, furniture and paper (10 tests)
  - BRE: deep compartiment (9 tests)
  - CTICM: hotel (3 tests)
  - CTICM: school (1 tests)
  - BRE: NFSC2 series (8 tests)
  - VTT: wooden structure (4 tests)

Example of calculation with natural fire

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EPFL-BI building in Ecublens

Natural fire

Description of the problem

Following the complete transformation of the BI building, a Natural Fire - Thermal Action study was carried out to verify the resistance of the structure located under the building inside the restaurant.

This verification was carried out following the requirement of a resistance of 60 minutes (R60) required by the AEAI fire protection directives, in view of the use of this room (large number of people).

Natural fire

AEAI 2003 Load-Bearing Switchboard with Sprinkler

Nombre de niveaux hors terre / Affectation	2 jusqu'à 600 m² cb [1] jusqu'à 1200 m² icb	2 plus de 600 m² cb [1] plus de 1200 m² icb	3	4	5 – 6	7 – 8 sans les bâtiments élevés
• Bâtiments d'habitation • Bâtiments administratifs • Bâtiments scolaires	incombustible [2] / combustible [2]	**incombustible** [2] / **combustible** [2]	**incombustible** [2] / **combustible** [2]	**R 30 (icb)** / **R 30**	R 60 (icb) / **R 60** [4]	R 60 (icb)
• Locaux industriels/ artisanaux q inférieur ou égal à 1000 MJ/m²	incombustible [2] / combustible [2]	**incombustible** [2] / **combustible** [2]	**incombustible** [2] / **combustible** [2]	**R 30 (icb)** / **R 30**	R 60 (icb) / **R 60** [4]	R 60 (icb)
• Locaux industriels/artisanaux q > 1000 MJ/m² • Bâtiments à affectation inconnue	**incombustible** [2] / **combustible** [2]	**R 30 (icb)** / **R 30**	**R 30 (icb)** / **R 30**	**R 60 (icb)**	**R 60 (icb)**	**R 60 (icb)**
• Etablissements hébergeant des personnes [a] p. ex. hôpitaux	R 60 (icb)	R 60 (icb)	R 60 (icb)	R 60 (icb)	R 60 (icb)	R 60 (icb)
• Etablissements hébergeant des personnes [b] p. ex. hôtels	**R 30 (icb)** [5] / **R 30** [5]	**R 30 (icb)** [5] / **R 30** [5]	**R 30 (icb)** [5] / **R 30** [5]	R 60 (icb)	R 60 (icb)	R 60 (icb)
• Bâtiments avec locaux prévus pour un grand nombre d'occupants • Grands magasins [c]	**incombustible** [2] / **combustible** [2]	R 30 (icb) / R 30	R 60 (icb)	R 60 (icb)	R 60 (icb)	R 60 (icb)
• Parkings • Garages pour véhicules à moteur	incombustible [2] / combustible [2]	**incombustible** [2] / **combustible** [2]	**incombustible** [2] / **combustible** [2]	**R 30 (icb)** ou incombustible [2] [3] / **R 30**	R 60 (icb) ou incombustible [2] [3] / **R 60** [4]	R 60 (icb) ou incombustible [2] [3]

Système porteur en matériaux incombustibles
Système porteur en matériaux combustibles

Tableau 2

Gras: Exigences réduites si installations sprinklers

Indeed, no fire resistance requirements are required for the rest of the building, depending on its use and the presence of an automatic extinguishing system.

Natural fire

General view of the restaurant.

View of the part of the restaurant, located under the BI building.

Natural fire

Detail of the glass façade.

HEB 240 boxed post CS-08.

Natural fire

View of the glass façade overlooking the patio.

Partition wall between the restaurant, the back office and the toilets.

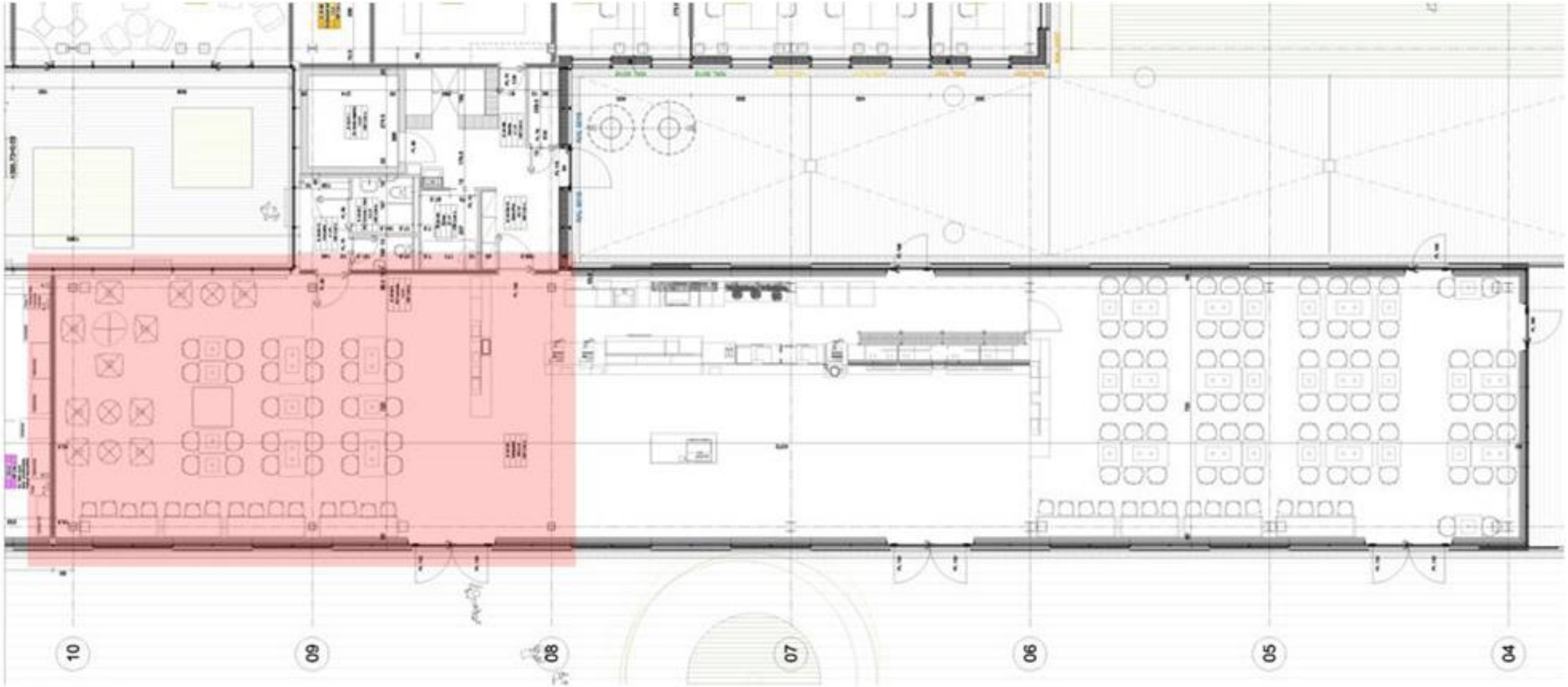
Natural fire

Sprinkler.

Focus on triple glazing.

Natural Fire – Study Perimeter

Following the requirement of an R60 resistance of the restaurant structure, we established the scope of the study in agreement with the fire protection authority.



Structure avec exigence R60

Natural Fire – Study Perimeter

The restaurant is 8.40 m wide and 45 m long. The ceiling height is 3.70 m.

Natural Fire – Study Perimeter

Assuming that the structure of the restaurant on one level is R0, the structure to be checked is the one located under the BI building on level 0. This is between the CR-CS/8-10 axes.

The structure studied is composed of steel columns in H-profile, boxed with metal plates.

The HEA 400 main windchests are continuous over the total length of the building, with a span of 7.20 m’.

The IPE 360 beams, with a span of 7.20 m', are supported between the windchests.

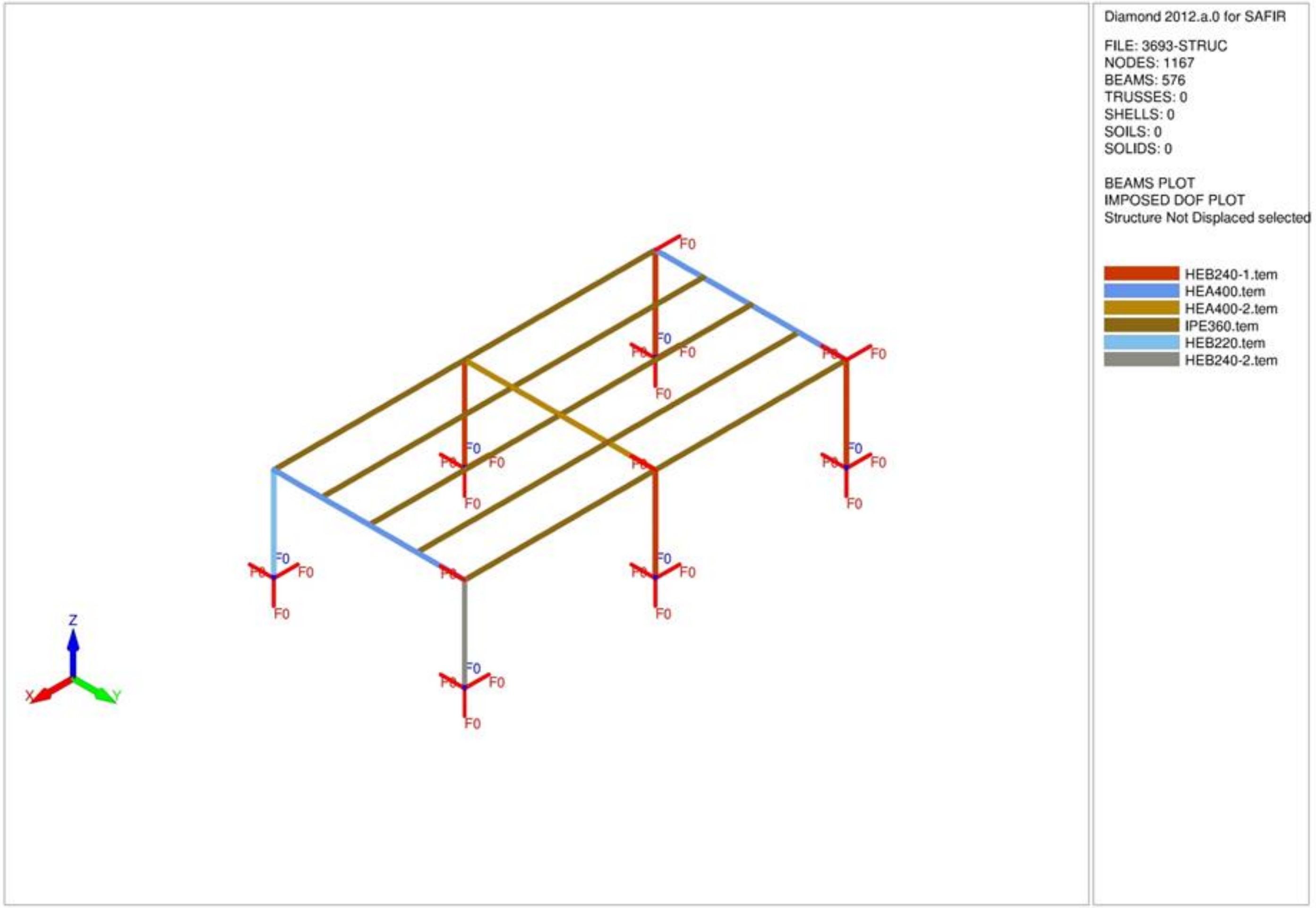
Natural fire - materials

The characteristics of the materials are as follows:

- HEA 400 S 235 Main Beams
- IPE 360 S 235 Transverse beams
- HEB 220 or HEB 240 S 235 columns boxed by plates thickness 10 to 12 mm S 235
- Holorib HR 51 concrete slab on sheet metal, 11 cm thick.

The general bracing of the building is provided by the two concrete cores located on either side of the building.

Natural fire - structure



As there are no indications on the plans, we did not consider that the beams were connected to the concrete slab. There is therefore no membrane effect.

Natural fire - actions

The following loads were applied to the structure studied.

•	Self-weight	HEA 400	1.25 kN/m’
		IPE 360	0.57 kN/m
		HEB 220 + 2 (200/12)	1.09 kN/m’
		HEB 240 + 2 (220/10)	1.18 kN/m’
		HEB 240 + 2 (220/15)	1.35 kN/m’

- Composite slab with sheet metal HR 51, ép. 11 cm 2.75 kN/m²
- Isolation 2 cm + concrete cover 7 cm 1.70 kN/m²
- Galandages 0.50 kN/m²

- Use load, cat. B (office) 3.00 kN/m²

Natural fire - actions

"Cold" floor loading

$$E_{d,ELU} = 1.35 \cdot (0.66 + 2.75 + 1.70 + 0.50)kN/m^2 + 1.5 \cdot 3.0kN/m^2 = 12.1\ kN/m^2$$

"Hot" floor loading

In an accident situation, in accordance with Art. 4.4.3.5 and in Table 2 of Appendix A of SIA 260, the value of $\varphi_2 = 0.3$

$$E_{d,fi} = 1.00(0.66 + 2.75 + 1.70 + 0.50)kN/m^2 + 1.0 \cdot 0.3 \cdot 3.0\ kN/m^2 = 6.51\ kN/m^2$$

Natural fire - actions

Difference in Load

$$\eta_{fi} = \frac{E_{d,fi}}{E_{d,ELU}} = \frac{6.51\ kN/m^2}{12.1\ kN/m^2} = 0.54$$

Between the situation at 20 °C and the accident case, a correctly dimensioned "cold" element will therefore have a resistance reserve of nearly 45% in a fire situation.

Physical Parameters Needed for Natural Fire Models

- Wall properties
- Plan dimension of the compartment
- Ceiling height
- Surface area of openings

Geometry

- Surface area of the fireplace
- Heat flow rate

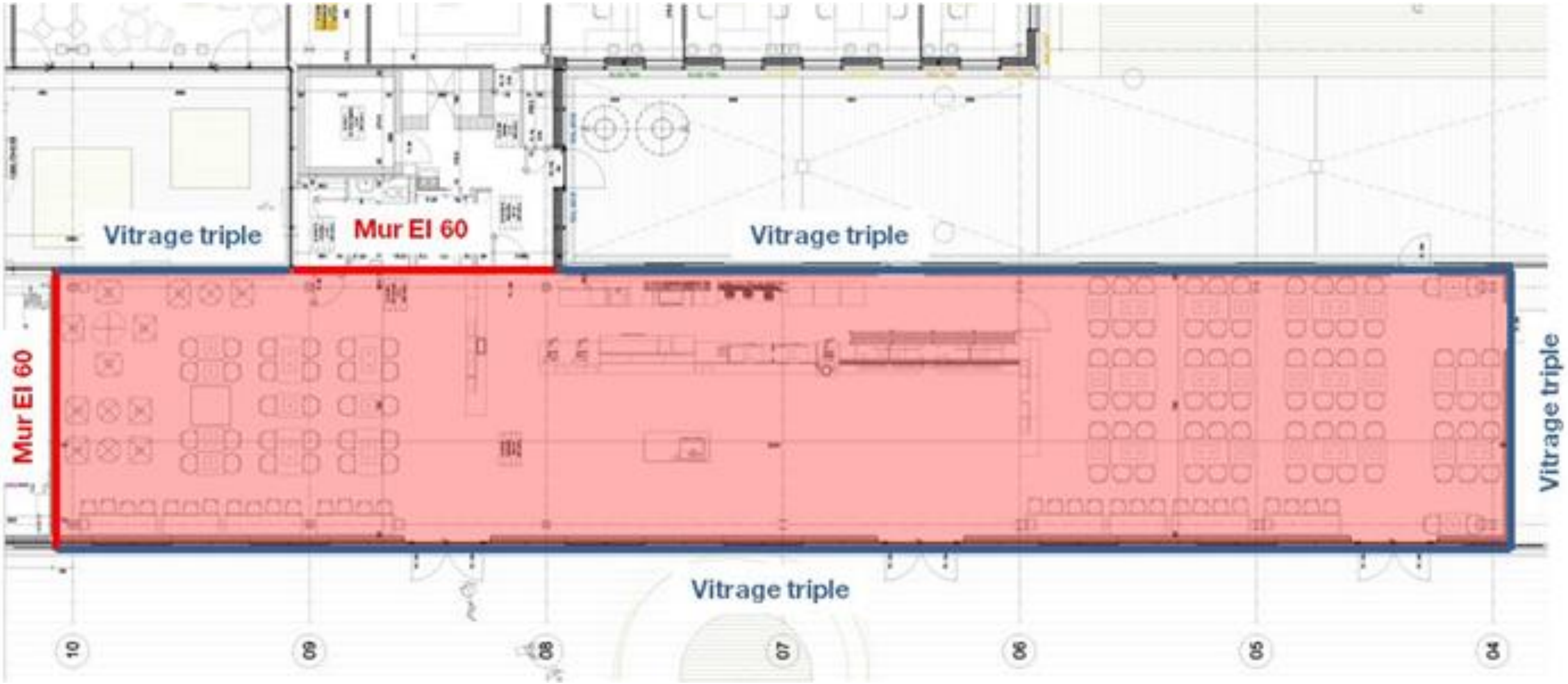
Fire

Natural Fire - Compartment

Following a discussion with the ECA, we have selected two study perimeters to calculate the Natural Fire - Thermal Action according to Annex E of Eurocode 1991-1-2.

Natural Fire - Compartment

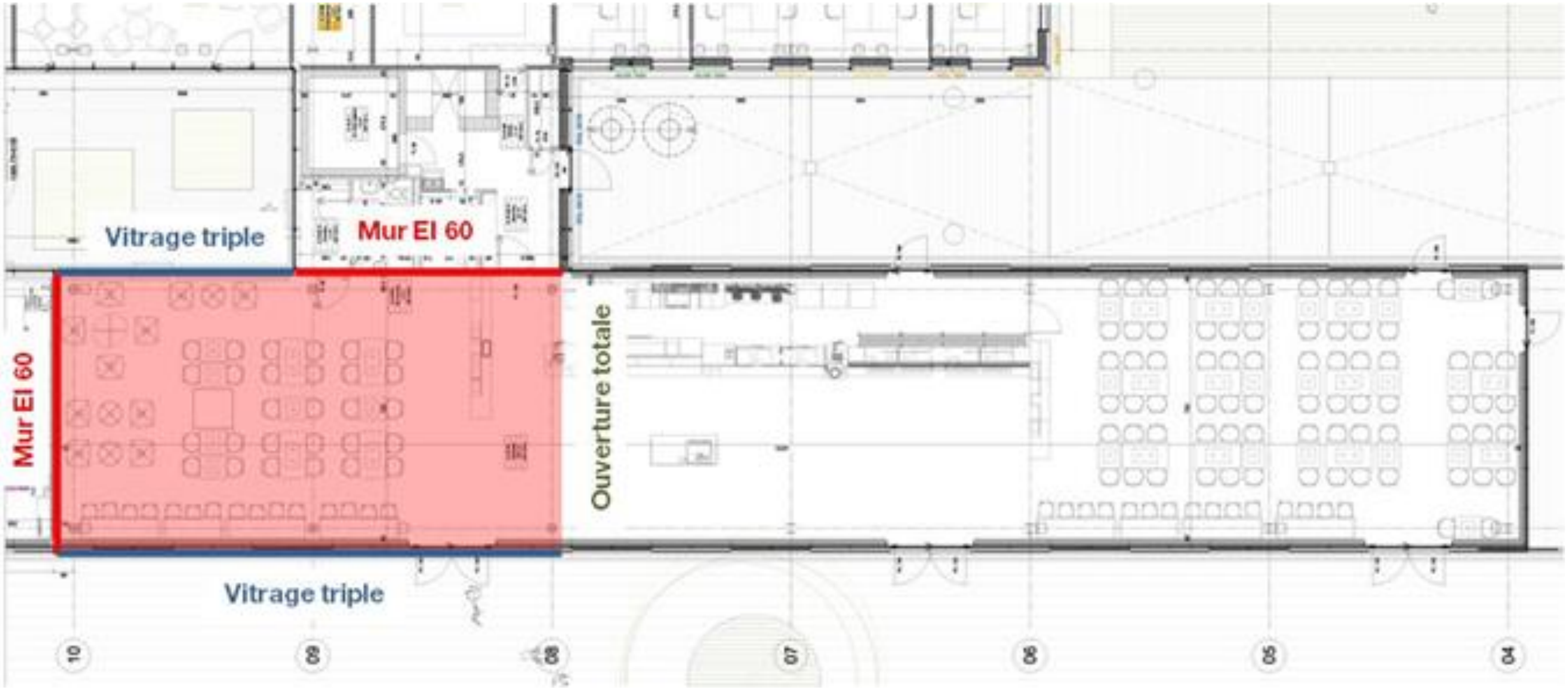
Variant 1 – Real compartment



Width : 8.40 m
Length : 45.0 m
Height : 3.70 m

Natural Fire - Compartment

Variant 2 – Fictious compartment



Width : 8.40m
Length: 15.0 m
Height : 3.70 m

Natural Fire - Compartment

Compartment

In the Natural Fire - Thermal Action model, it is assumed that the fire remains confined to the compartment.

For this, the walls must have a fire resistance in accordance with the fire protection (EI) guidelines.

Due to the complexity of the other methods and the lack of experimental data to determine the resistance of the walls under a Natural Fire - Thermal Action scenario, it is accepted that the EI resistance given for an ISO fire is also sufficient for a Natural Fire - Thermal Action scenario.

Natural Fire - Compartment

Thermal characteristics of the walls

- Temperature losses through heat transfer through the walls are important elements.
- They occur by convection and radiation.
- The thermal properties of the walls must be known, if possible at high temperatures.
- If the characteristics at high temperatures are not known, then the 20°C temperature should be used.
- The effect of moisture in materials is neglected.
- The thickness of the different materials must be known.

Natural Fire - Compartment

Openings

- The severity of a fire depends on the number of openings. These are made up of doors, windows and roof skylights.
- Doors are considered closed if there are other openings (min 10% open).
- Doors are considered open if there are no other openings.
- Doors and glazing with EI resistance are considered destroyed after the resistance time (30, 60 minutes).

Natural Fire - Compartment

Definition of openings for our case

Partition walls

- The EI60 partitions are considered to be intact for the duration of the fire.

Doors

- The EI30 doors, to the toilet and preparation rooms, are considered closed throughout the simulation. Indeed, as the building is very glazed, these two small openings do not change the calculation of the temperatures inside the compartment.

Natural Fire - Compartment

Windows

Triple-glazed windows in a steel frame were considered under the following two scenarios:

Scenario 1

- 90% of the glazing surface is considered open from the start of the fire. This scenario covers the breakage of the glazing caused by the intervention of the firefighters.

Scenario 2

- At 300 °C, 50% of the surface of the glazing exposed to this temperature is assumed to be complete openings. At 500 °C, 90% of the glazing area exposed to this temperature is considered open.

Natural Fire - Compartment

Mechanical ventilation

If heat and smoke evacuation is present, this can be taken into account for localized fires.

On the other hand, these installations must be considered non-operational in the event of a fully developed fire. Indeed, temperatures of around 600°C are reached very quickly, which is above the expected operating temperatures.

Comfort ventilation should be switched off in the event of a fire alarm.

In our case, no installation is present.

Natural fire – thermal action

Heat load density

- After analysis of the present fire load, we have accepted a characteristic value of:

$$q_{f,k} = 511\ MJ/m^2$$

Maximum Heat Flow (RHRf)

- The maximum heat flow rate is 250 kW/m².

Speed of propagation

- The speed of propagation is average, i.e. $t_\alpha = 300\ s$.

Natural fire – fire charge

	Stand Deviation	Average	80 % fractile	90% fractile	95 % fractile
House	234	780	948	1085	1217
Hospital	69	230	280	320	359
Hotel (room)	93	310	377	431	484
Library	450	1500	1824	2087	2340
Office (standard)	126	420	511	584	655
School	85,5	285	347	397	445
Shopping mall	180	600	730	835	936
Theater, cinema	90	300	365	417	468
Transport (public area)	30	100	122	139	156

Fire load data for different uses [MJ/m^2] according to Annex E standard EN 1991-1-2

Fire charge - example

- Example
- Euro Wooden Pallet – SBB
  - Average weight 25 kg
  - Lower calorific value of wood

$$\Delta_c H^0 = 17.5\ MJ/kg$$

$$Q_f = m \cdot \Delta_c H^0 = 25\ \text{kg} \cdot 17.5\ MJ/kg = 438\ MJ$$

  - Pallet surface 1.20 m / 0,80 m = 0.96 m^2

$$q_{f,k} = \frac{Q_f}{A} = \frac{438\ MJ}{0.96\ m^2} = 456\ MJ/m^2$$

Natural fire – thermal action

Rate of Heat Release (RHR)

The fire load gives the available energy, but the temperature of the gases depends on the RHR which defines the rate at which the energy is released.
The same fire charge can either burn very quickly or smoulder for a long time, resulting in completely different gas temperatures.

The RHR is defined by the following law:

$$\boldsymbol{RHR = (t/t_{\alpha})^2}$$

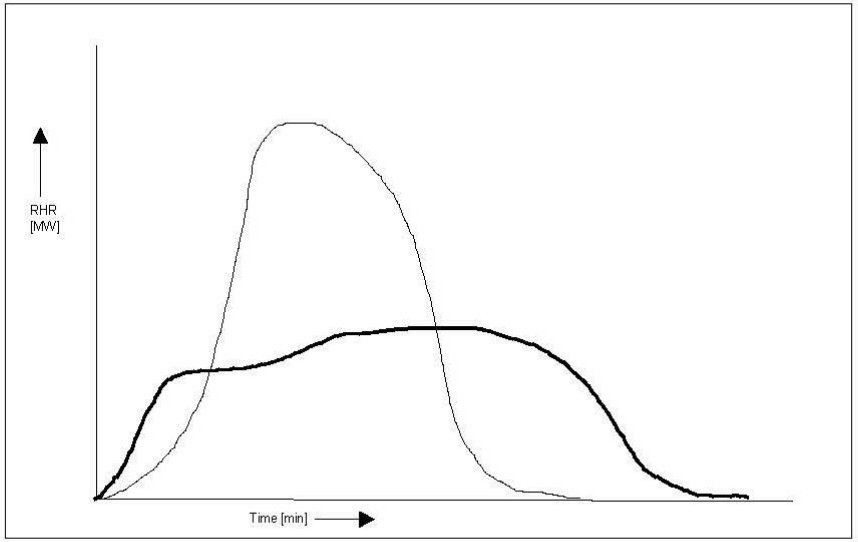
RHR: Rate of Heat Release of fire in its growth phase [MW]
t: time [s]
t_{α}: Time constant depending on the type of assignment [s]

Natural fire – thermal action

Two RHR curves corresponding to the same fire load.

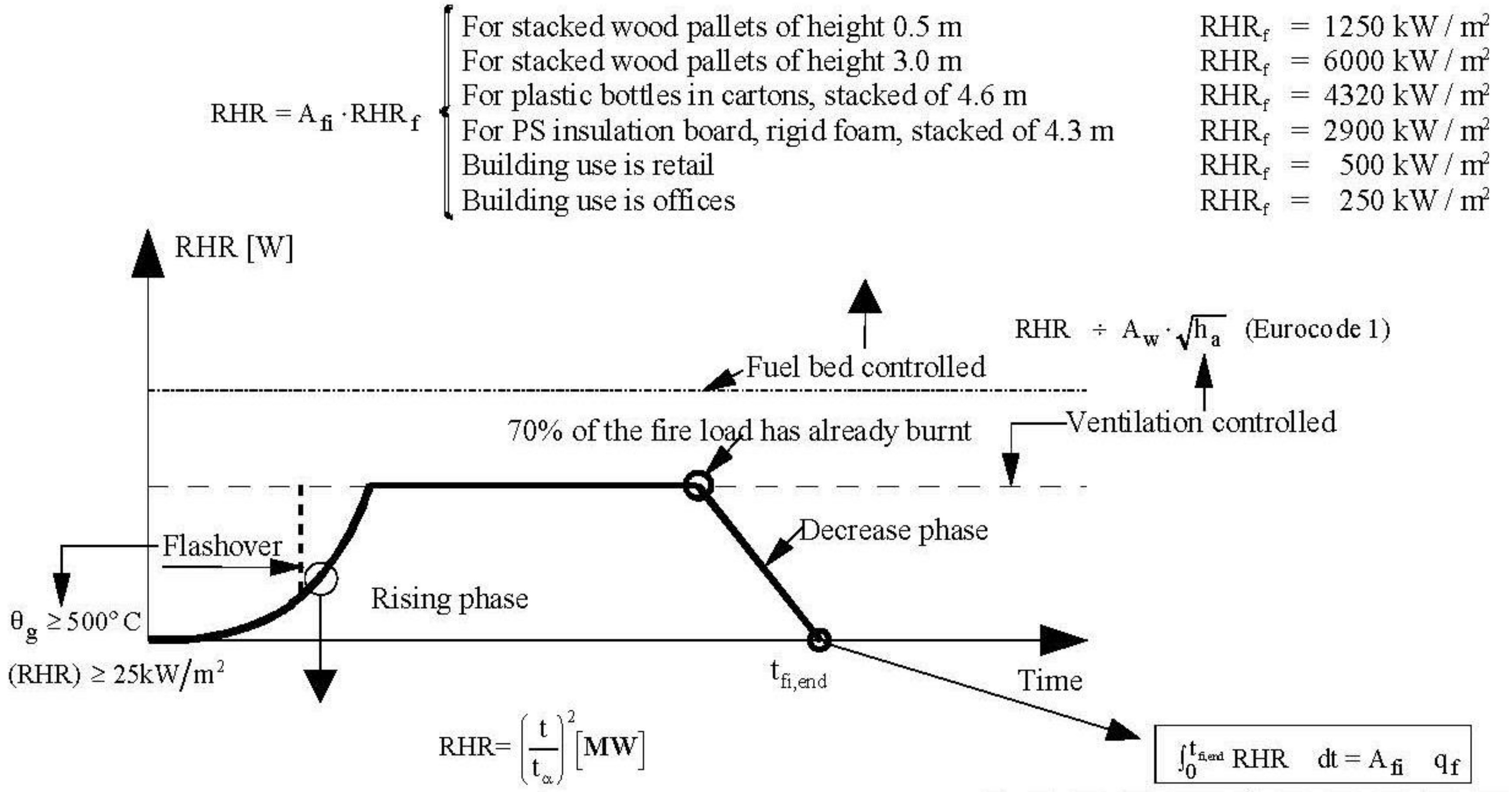
After the growth phase, the RHR curve extends into a horizontal plateau with a value that is a function of:

- The fire load if the oxygen supply is sufficient (fuel controlled fire).
- Ventilation conditions if openings are not sufficient (fire controlled by ventilation).



- Following laboratory tests, the decay phase begins when 70% of the fire charge is consumed.

Natural fire – thermal action



Natural fire – thermal action

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Fire Growth Rate t_α depending on the assignment

Assignment / activity	Growth rate	Constant t_α [s]
Exhibition Gallery	Slow	600
Storage (low fuel)	Slow	600
Housing	Medium	300
Hotel (room)	Medium	300
Office	Medium	300
Storage (cotton, polyester mat)	Medium	300
Store	Fast	150
Storage (mail bag, plastic foam, stacked wood)	Fast	150
Chemical plant	Very fast	75
Storage (alcohol, upholstered furniture)	Very fast	75

Design Load - Fire

Tableau E.1 — Coefficients δ_{q1}, δ_{q2}

Surface de plancher du compartiment A_f [m²]	Risque d'activation du feu δ_{q1}	Risque d'activation du feu δ_{q2}	Exemples de types d'occupation
25	1,10	0,78	galerie d'art, musée, piscine
250	1,50	1,00	bureaux, résidence, hôtel, industrie papetière
2 500	1,90	1,22	fabrique de machines et de moteurs
5 000	2,00	1,44	laboratoire de chimie, atelier de peinture

$$q_{f,d} = \delta_{q1} \cdot \delta_{q2} \cdot \prod \delta_{ni} \cdot m \cdot q_{f,k}$$

Suppression automatique du feu				Détection automatique du feu			Suppression manuelle du feu				
Système d'extinction à eau automatique	Approvisionnements en eau indépendants			Détection automatique du feu et alarme		Alarme automatique transmise aux pompiers	Pompiers sur site	Pompiers hors site	Voies d'accès libres	Equipement de lutte contre le feu	Système de désenfumage
	0	1	2	par la chaleur	par la fumée						
δ_{n1}	δ_{n2}			δ_{n3}	δ_{n4}	δ_{n5}	δ_{n6}	δ_{n7}	δ_{n8}	δ_{n9}	δ_{n10}
0,61	1,0	0,87	0,7	0,87 ou 0,73		0,87	0,61 ou 0,78		0,9 ou 1 ou 1,5	1,0 ou 1,5	1,0 ou 1,5

Natural fire – thermal action

Fire Model

The light used for the calculation is a combination of two models:

- localized fire according to Hasemi's model (pre-flashover)
- Widespread fire to an area (post-flashover)

The software used is "Ozone, 2.2.6", developed by the University of Liège and Arcelor Research.

For the verification of the columns, as the localized fire models are still being studied, we used the standard ISO curve, which is on the safety side in this case.

Natural fire – thermal action

Boundary Conditions

The boundaries of the compartment were modelled with the wall materials, i.e. 15 cm brick with a 1 cm layer of plaster.

The upper parts of the glazing were modelled by a 16 cm insulation placed between two 0.1 cm steel sheets.

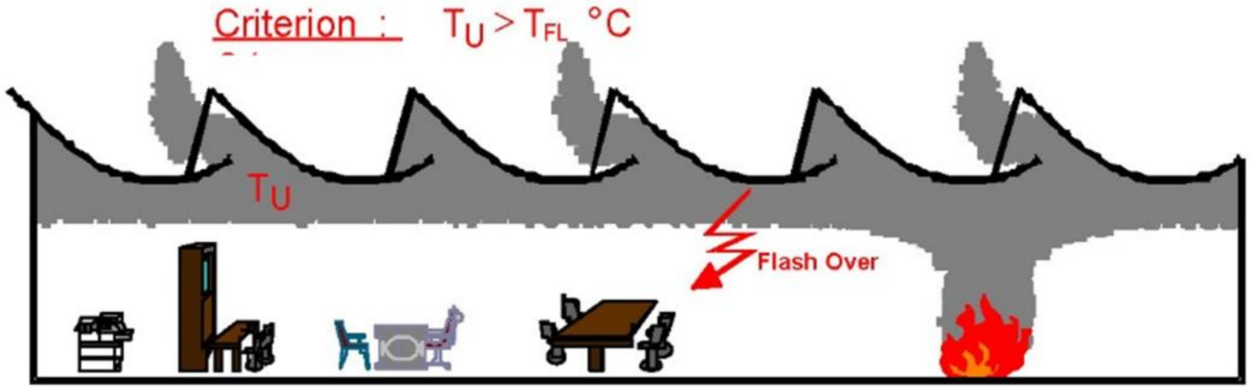
The glazing was modelled according to scenarios 1 and 2 defined in the opening chapter.

They are opened in stages according to the temperature of the room.

At time "t = 0", a 10% opening is present to model envelope leaks and promote fire activation.

Natural fire – thermal action

Flashover criteria



- 2 zones →1 zone, if the following criteria are met :
  - T_{smoke} > 500 °C
  - Combustible material in smoke and T_{smoke} > 300 °C
  - Localized fire > 25% of the compartment surface
  - Smoke > 80% of the compartment height

Natural fire – thermal action

The building is equipped with a water mist device, the efficiency of which is at least equal to that of the Sprinkler.

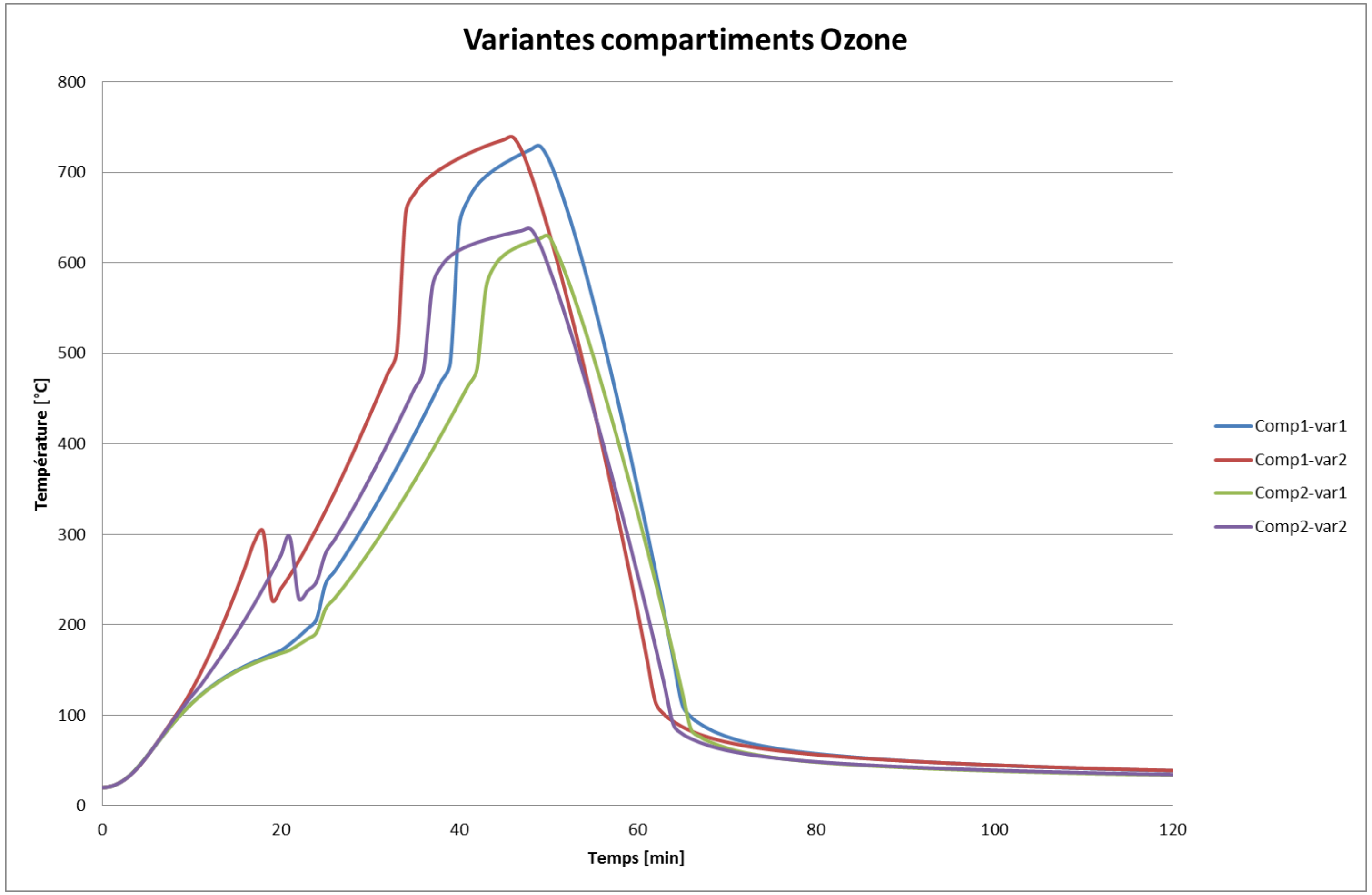
After discussion with the fire protection authority, the reduction factor $\delta_{n,1} = 0.61$ is accepted for this study, according to the value proposed in the Eurocode.

On the other hand, there is no discount for fire detection or company firefighters.
The fire design load for the entire compartment is therefore :

$$\boldsymbol{q_{f,d}} = \delta_{q,1} \cdot \delta_{q,2} \cdot \prod \delta_{n,i} \cdot m \cdot q_{fk}$$

$$\boldsymbol{q_{f,d}} = 1.58 \cdot 1.0 \cdot 0.61 \cdot 0.8 \cdot 511\, MJ/m^2 = 394\, MJ/m^2$$

Natural fire – thermal action

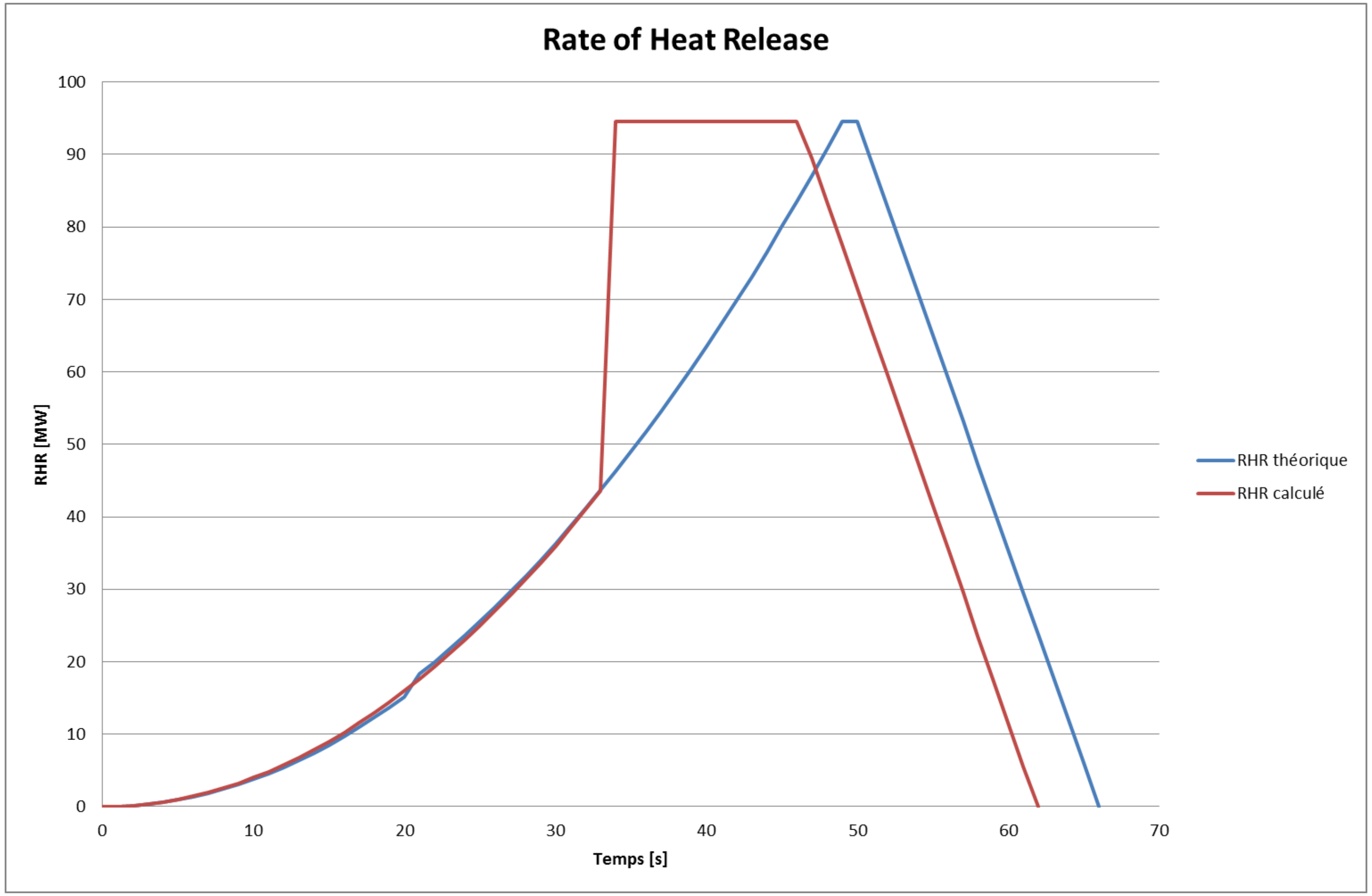


It can be seen that the fire in compartment 1 is more severe because the fire design load is taking into account in the factor δ_{n_1} the influence of the surface of the compartment.

Natural fire – thermal action

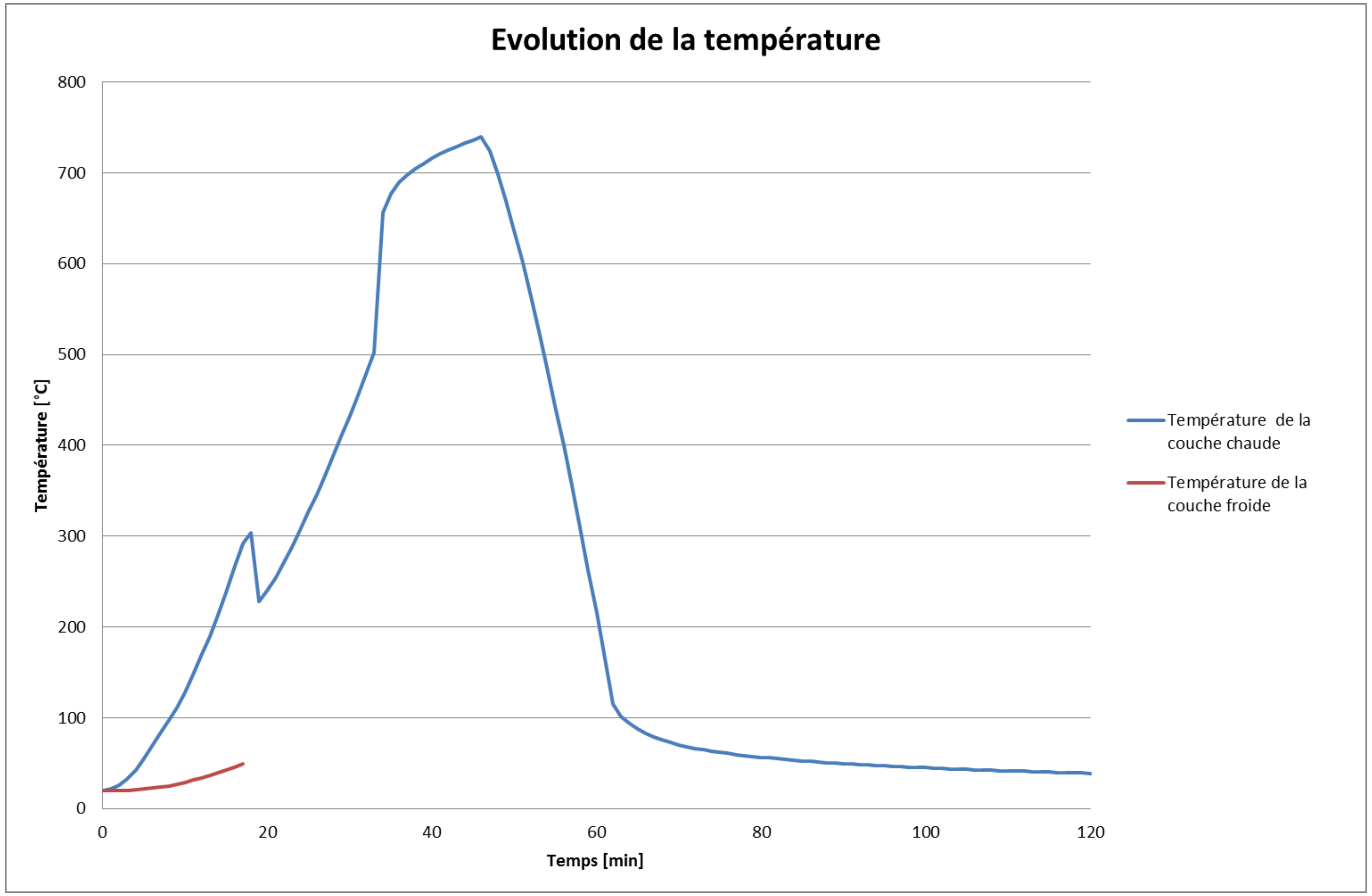
Scenario chosen, with the ISO curve by comparison. We also notice the influence of the Sprinkler.

Natural fire – thermal action



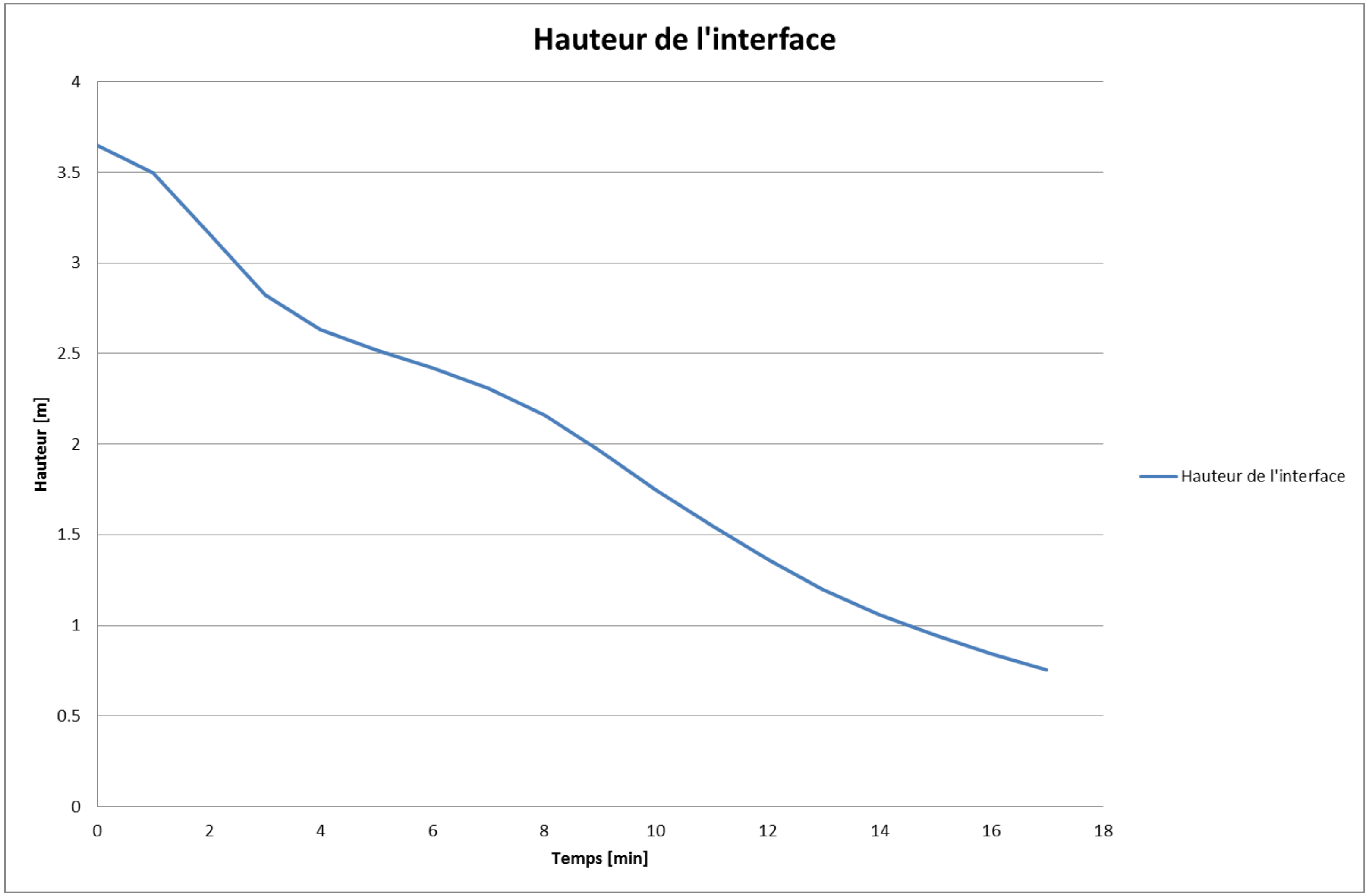
On these two curves, we can see the difference due to flashover on the calculated RHR curve compared to the theoretical one. This blaze occurred at 33 minutes.

Natural fire – thermal action



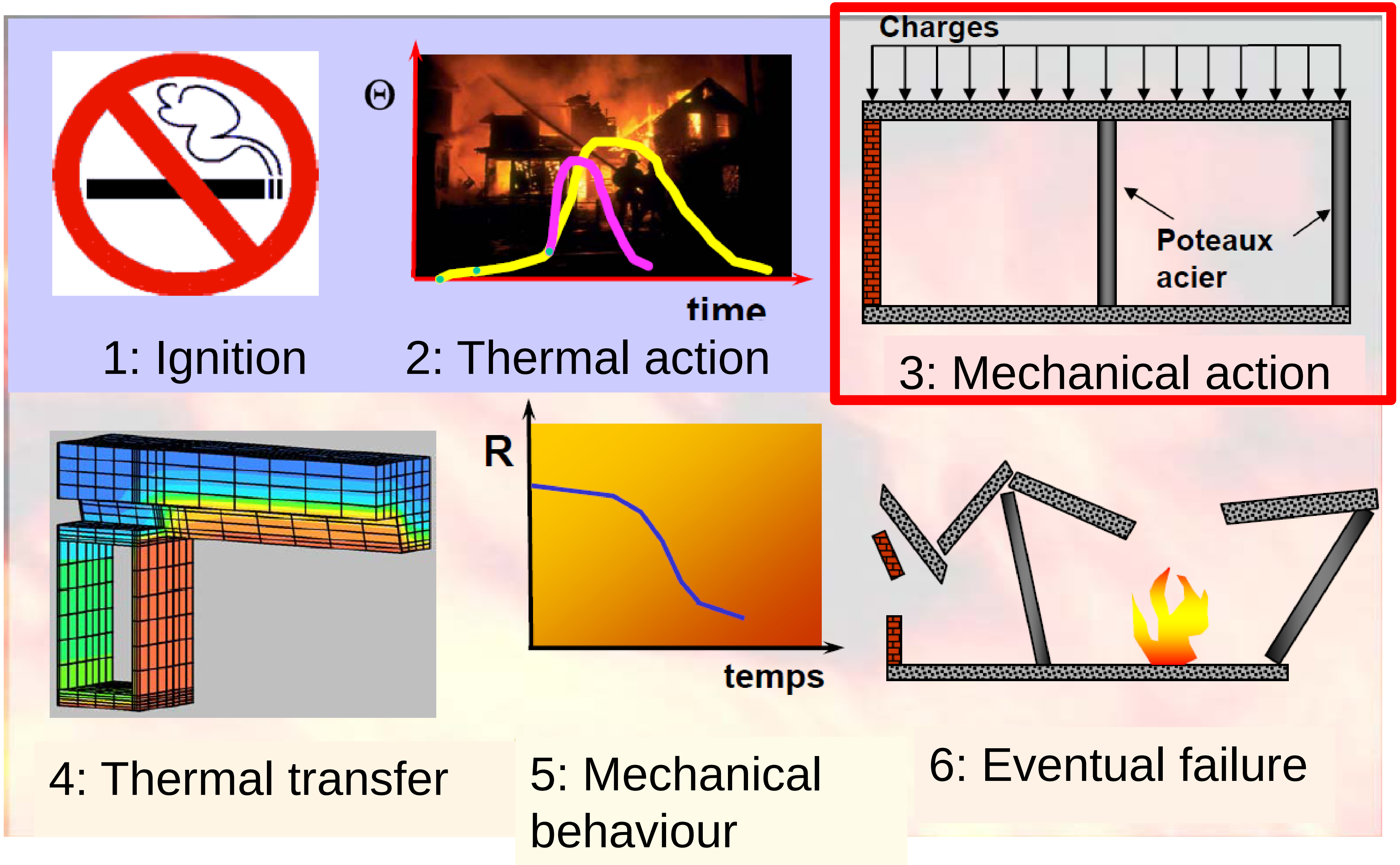
The maximum temperature of 736 °C is reached after 46 minutes. The model changes from two zones to one zone at 17 minutes. This is due to the smoke layer that reaches 0.75 m at 17 minutes, which is one of the conditions for the change of model.

Natural fire – thermal action



Mechanical action

Natural fire – mechanical action



Natural fire – mechanical action

The "cold" sizing action is written according to the SIA 260 standard

$$E_{d,ULS} = 1.35 \cdot g + 1.35 \cdot g' + 1.5 \cdot q$$

The "hot" design action is considered an accidental action according to the SIA 260 standard (same as earthquake).

$$E_{d,fi} = 1.00 \cdot g + 1.00 \cdot g' + \psi_2 \cdot q$$

The coefficient ψ_2 must be selected according to Table 2 of SIA 260.

With a coefficient ψ_2 varying between 0.3 and 0.8, it can be seen that a section correctly dimensioned when cold will have a resistance reserve between 30 and 50% higher in a "fire" situation.

Natural fire – mechanical action

The "cold" dimensioning action for the IPE 360 profile is valid in our case:

$$Ed_{,ULS} = 1.35 \cdot g + 1.35 \cdot g' + 1.5 \cdot q$$

The "hot" design action is considered an accidental action according to the SIA 260 standard (same as earthquake).

$$Ed_{,fi} = 1.00 \cdot g + 1.00 \cdot g' + \psi_2 \cdot q$$

The coefficient ψ_2 must be selected according to Table 2 of SIA 260.

For offices, the coefficient ψ_2 is 0.3.

Natural fire – mechanical action

The "cold" sizing action is written according to the SIA 260 standard

$$E_{d,ULS} = 1.35 \cdot g + 1.35 \cdot g' + 1.5 \cdot q$$

$$E_{d,ULS} = 1.35 \cdot 0.57\ kN/m' + 1.35 \cdot (2.75 + 1.70 + 0.50)\ kN/m^2 \cdot 1.80\ m' + 1.5 \cdot 3.00\ kN/m^2 \cdot 1.80\ m' = 20.90\ kN/m'$$

The "hot" design action is considered an accidental action according to the SIA 260 standard (same as earthquake).

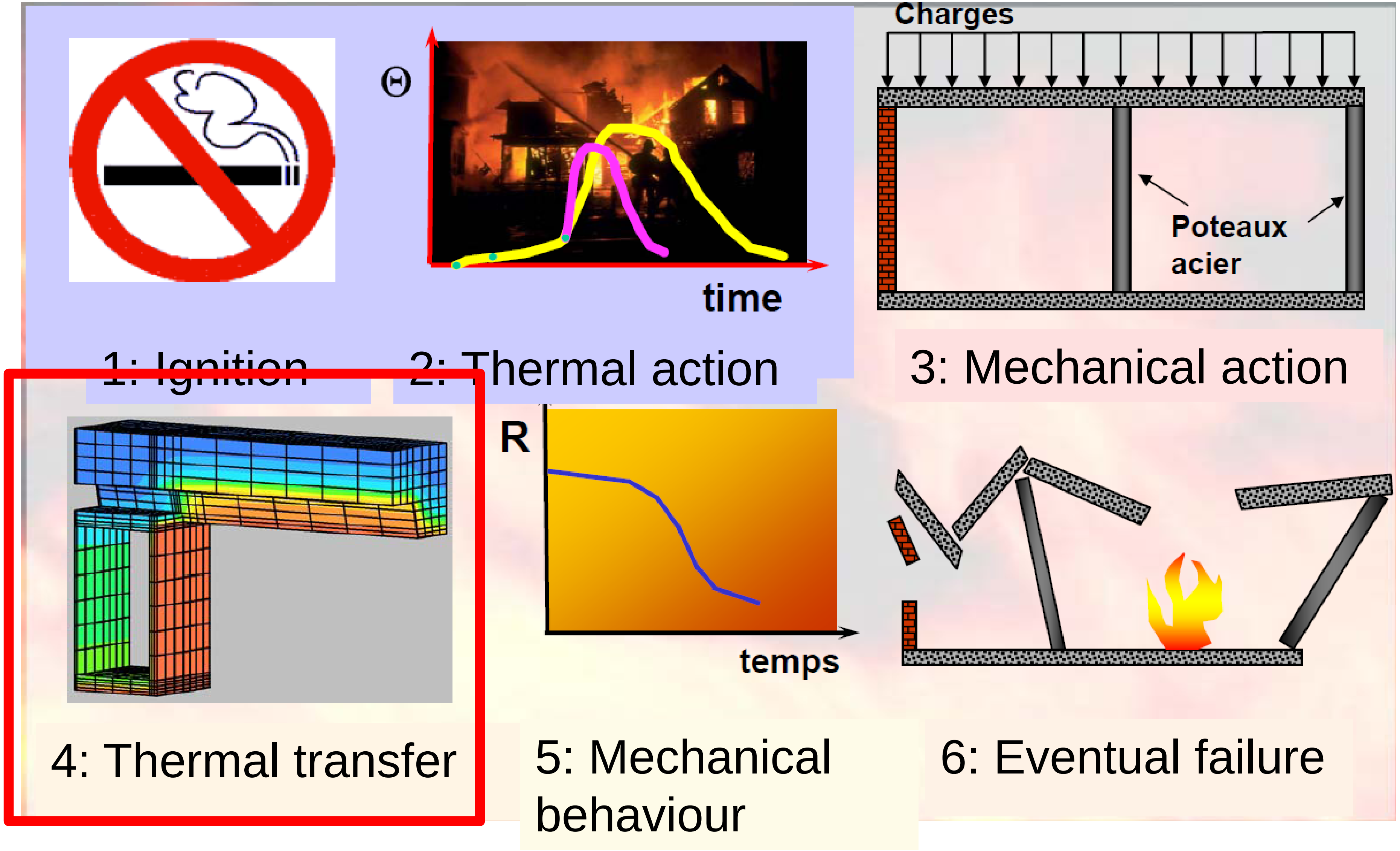
$$E_{d,fi} = 1.00 \cdot g + 1.00 \cdot g' + \psi_2 \cdot q$$

$$E_{d,fi} = 1.00 \cdot 0.57\ kN/m' + 1.00 \cdot (2.75 + 1.70 + 0.50)\ kN/m^2 \cdot 1.80\ m' + 0.3 \cdot 3.00\ kN/m^2 \cdot 1.80\ m' = 11.10\ kN/m'$$

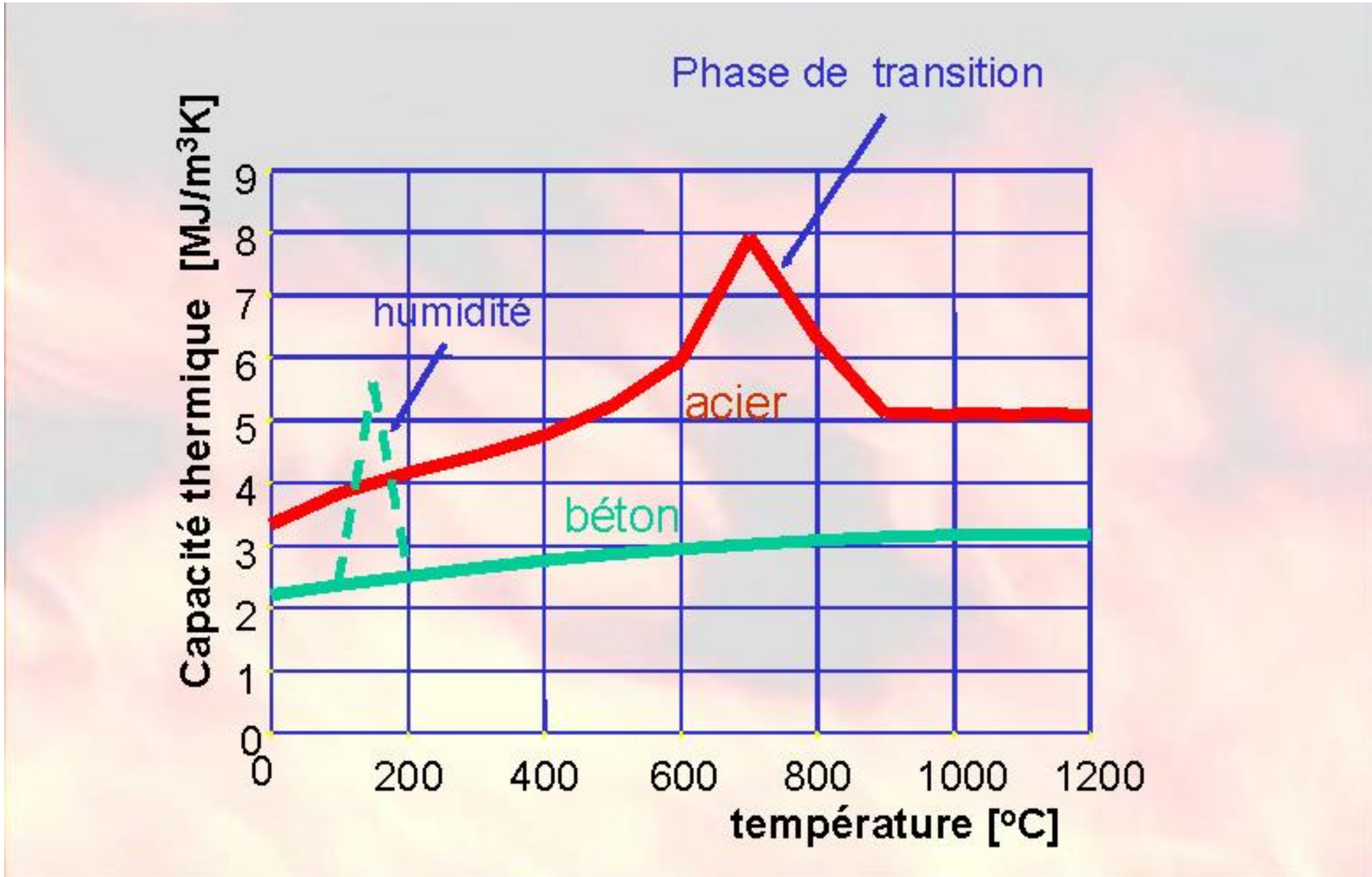
It should be noted that a section that is correctly dimensioned when cold will have a resistance reserve of about 50% in a "fire" situation.

Heat transfer

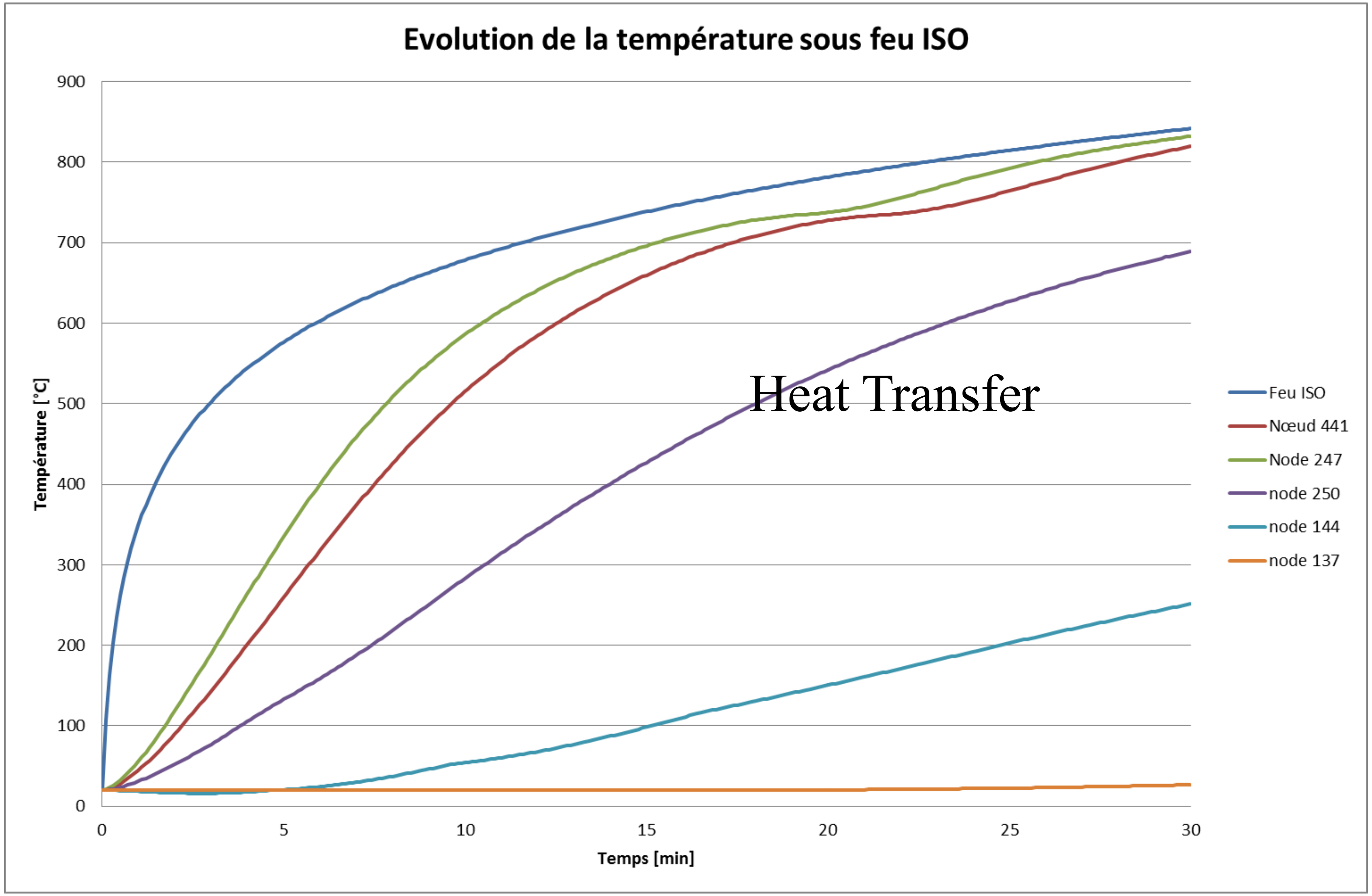
Natural fire – heat transfer

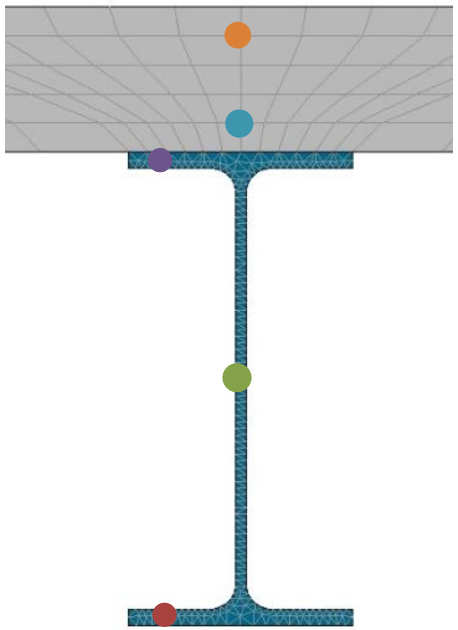


Heat Transfer

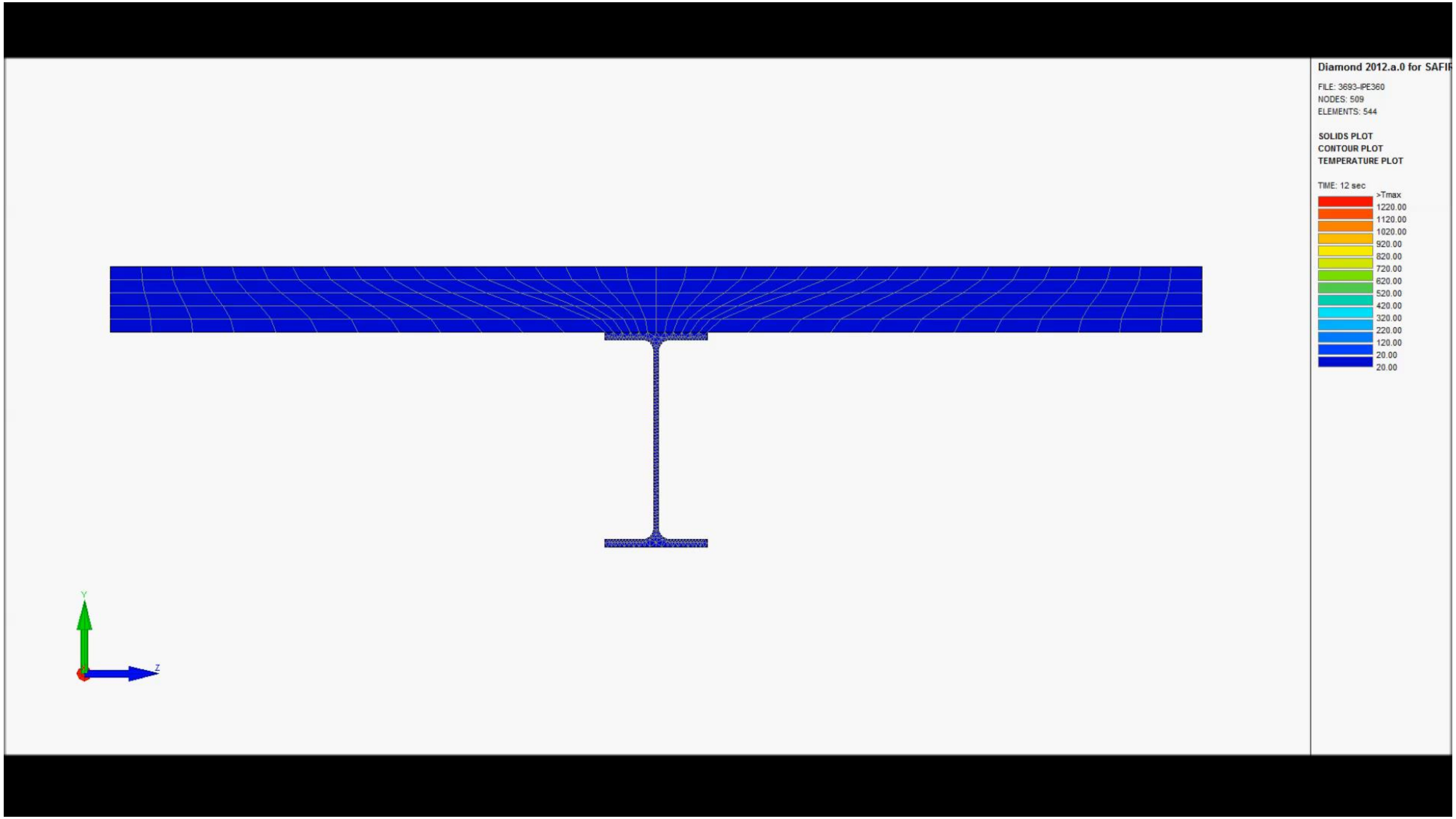


Heat Transfer

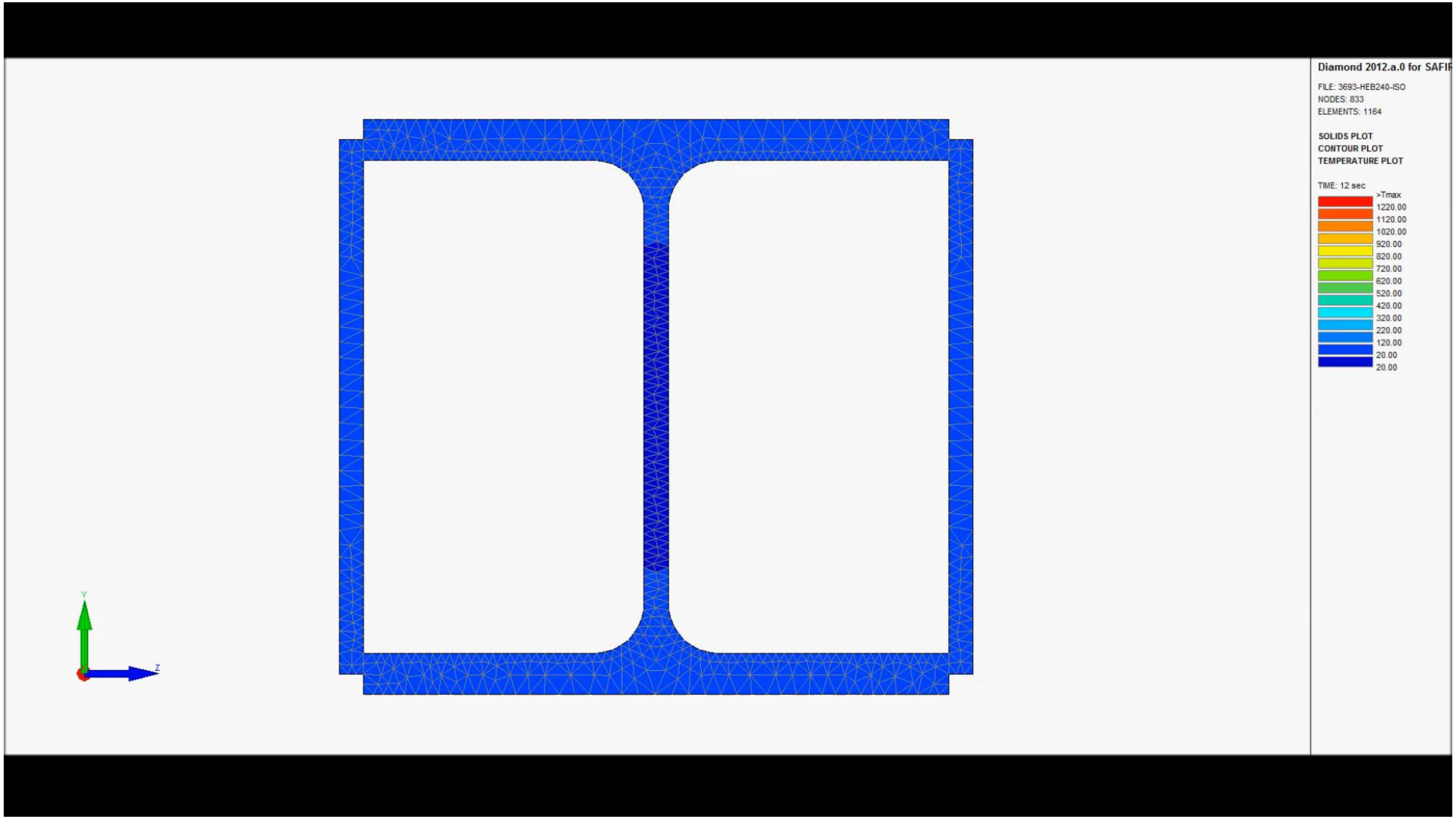




Heat Transfer

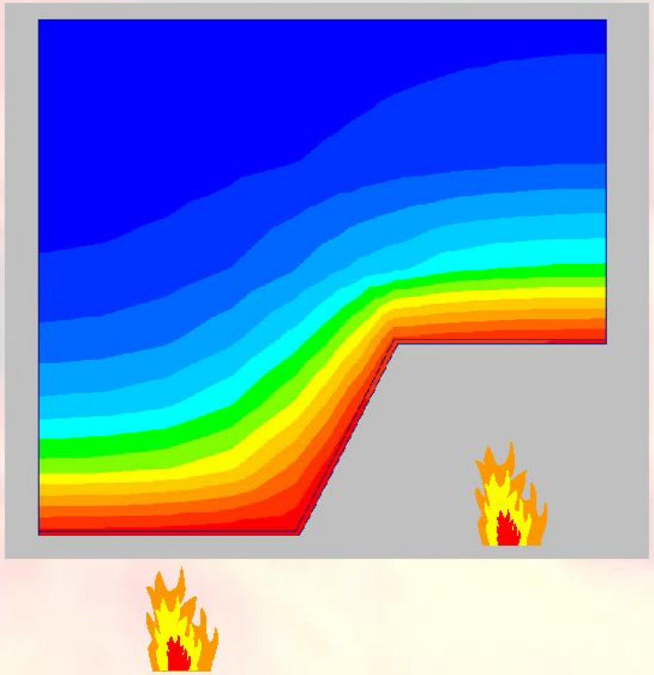


Heat Transfer

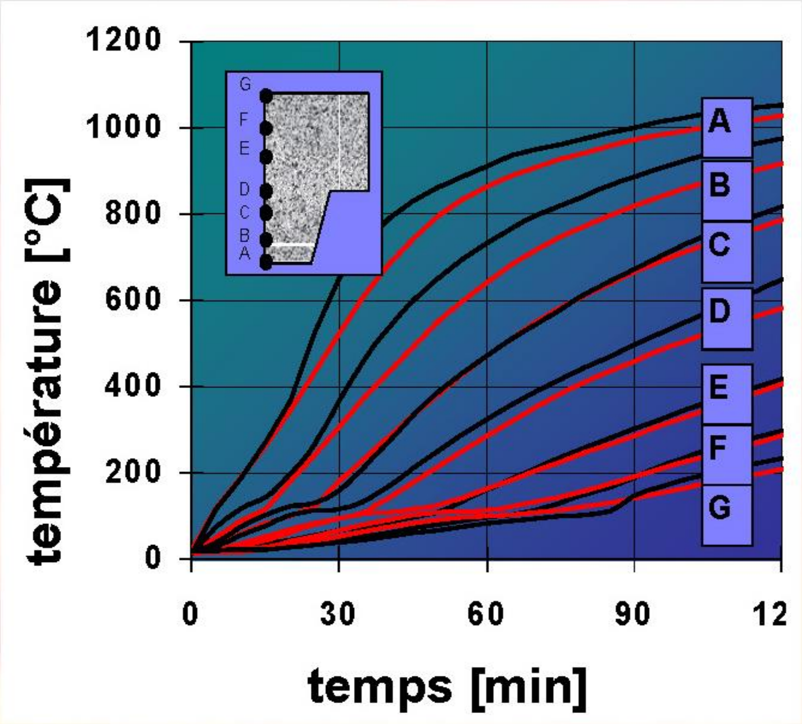


Heat Transfer

Temperature field, Composite floor (2D)



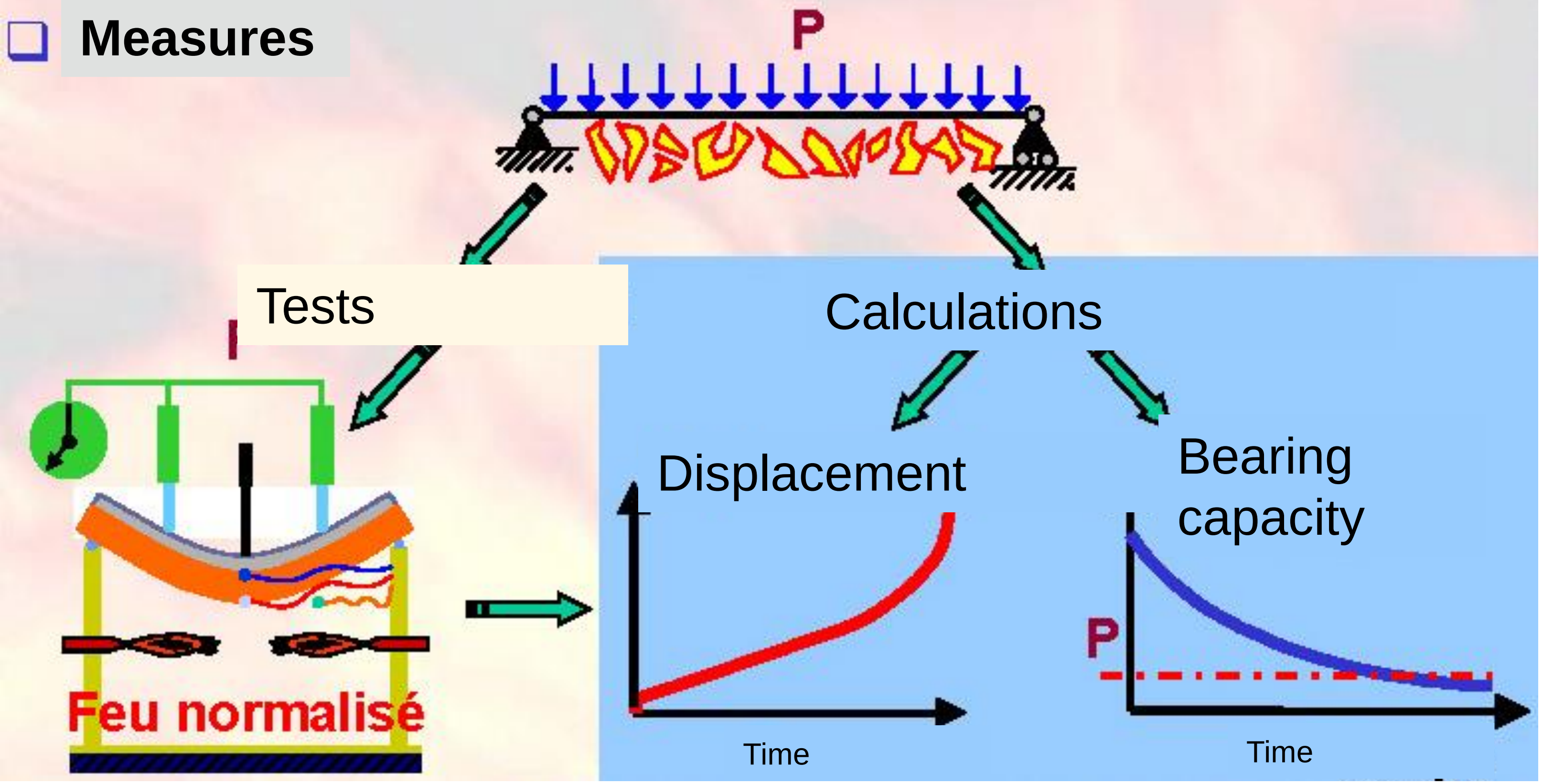
Numerical simulation



Theoretical and experimental results

Evaluation of the mechanical behaviour of structures in fire situations

- **Goal** :
  Describe the mechanical behaviour of structures subjected to fire
- **Measures**



Aspects relating to the analysis of the mechanical fire behaviour of structures

Fire Safety & Engineering SA

Mechanical loads in a fire situation

- Specific load combination

Mechanical properties of materials at elevated temperatures

- Stiffness and strength vary with temperature

Calculation of the fire resistance of structures

- Structural Analysis Approaches
- Calculation methods
- Application

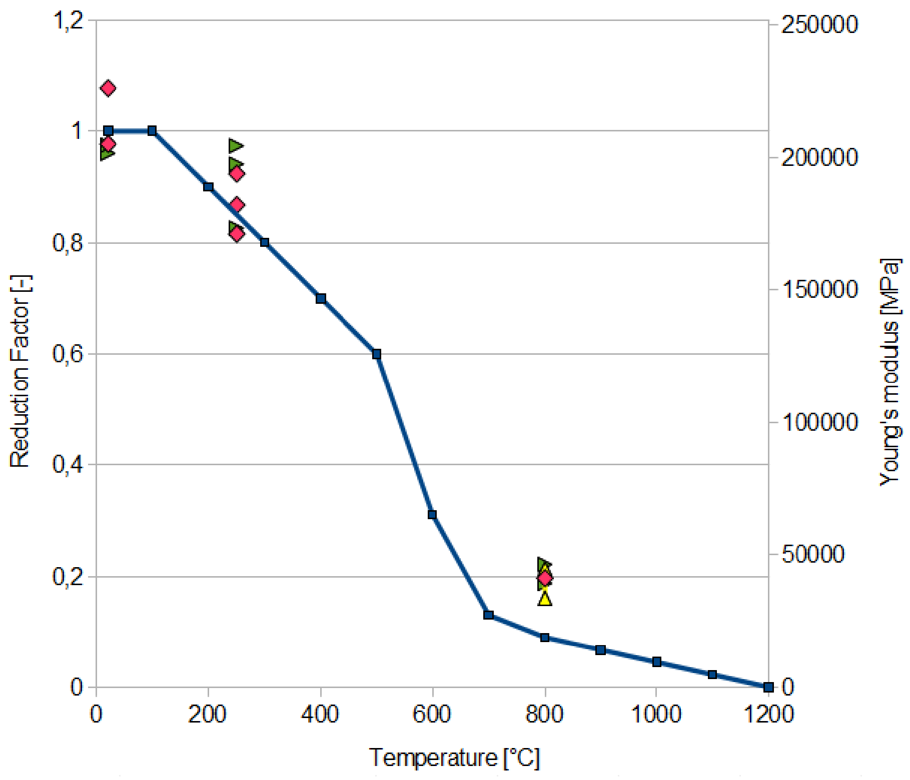
Specific fire resistance of steel structures

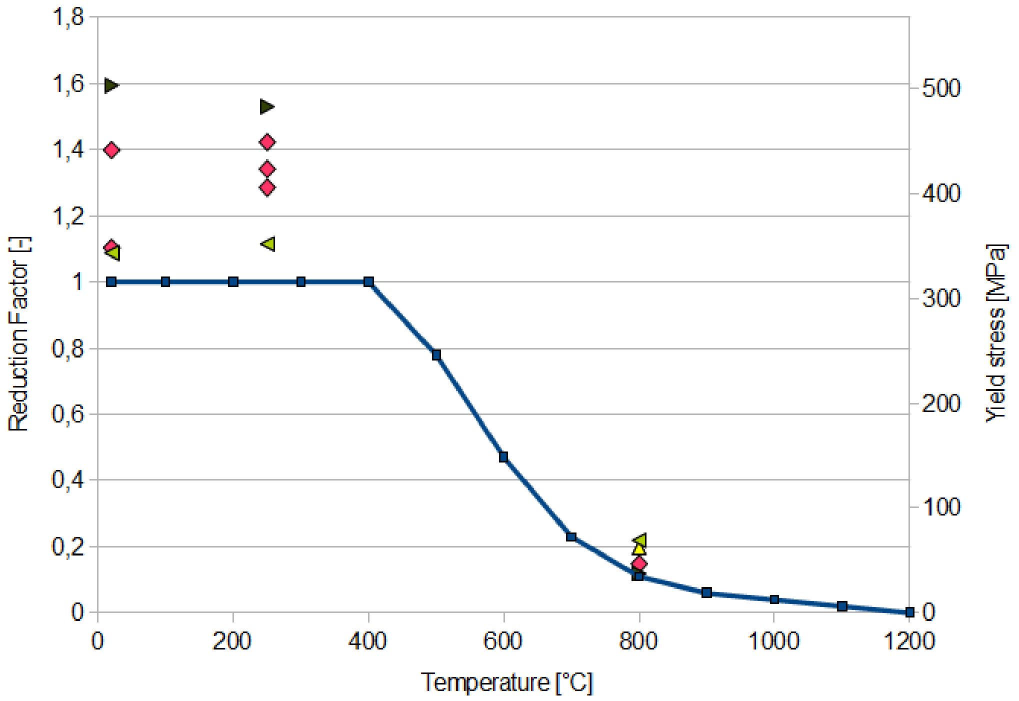
- Connections, welding, etc.

Mechanical behaviour

Mechanical properties of structural steel at high temperature levels (tests)

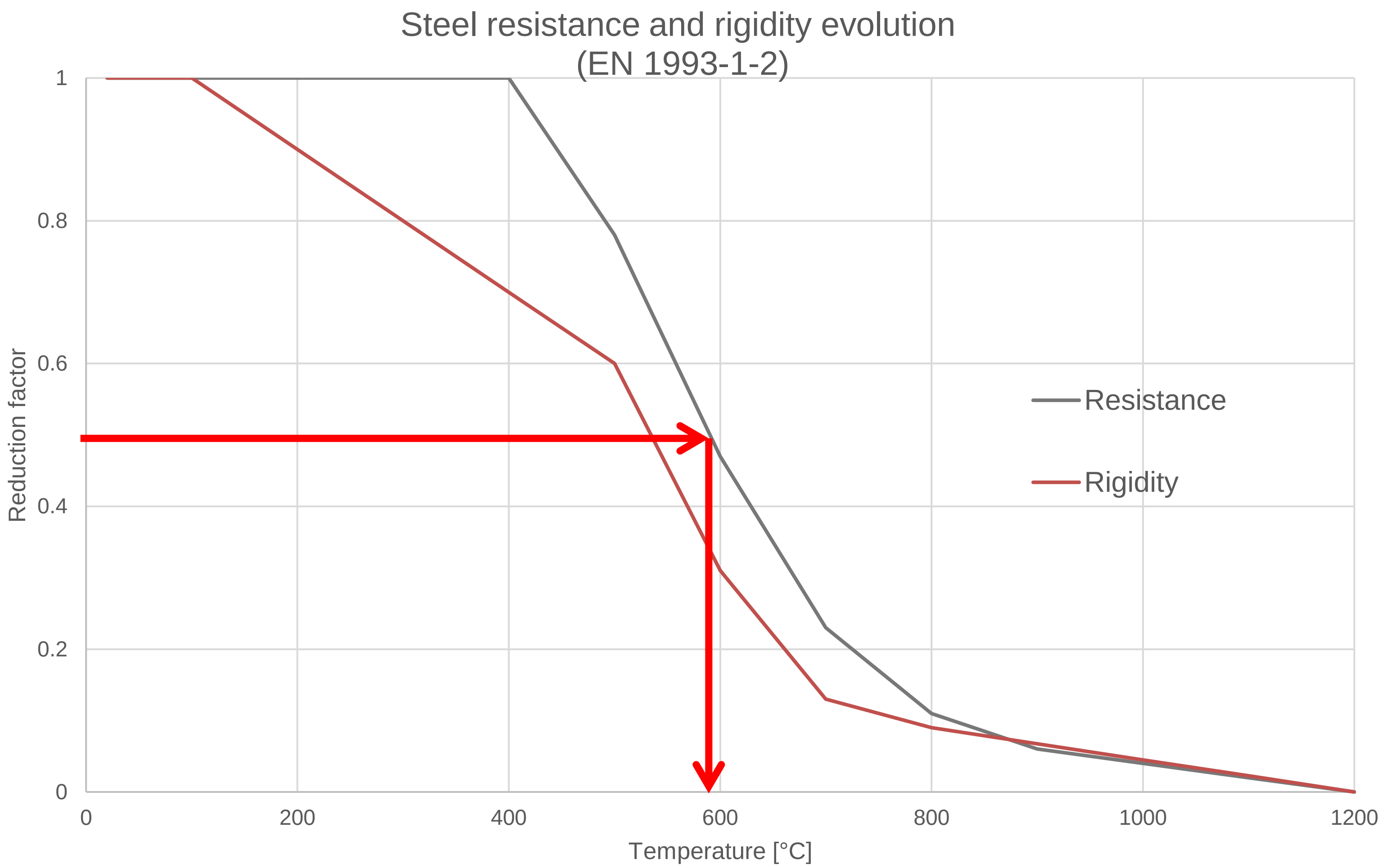
Structural steel S 355





Mechanical behavior

Mechanical Properties of Structural Steel – SN EN 1993-1-2

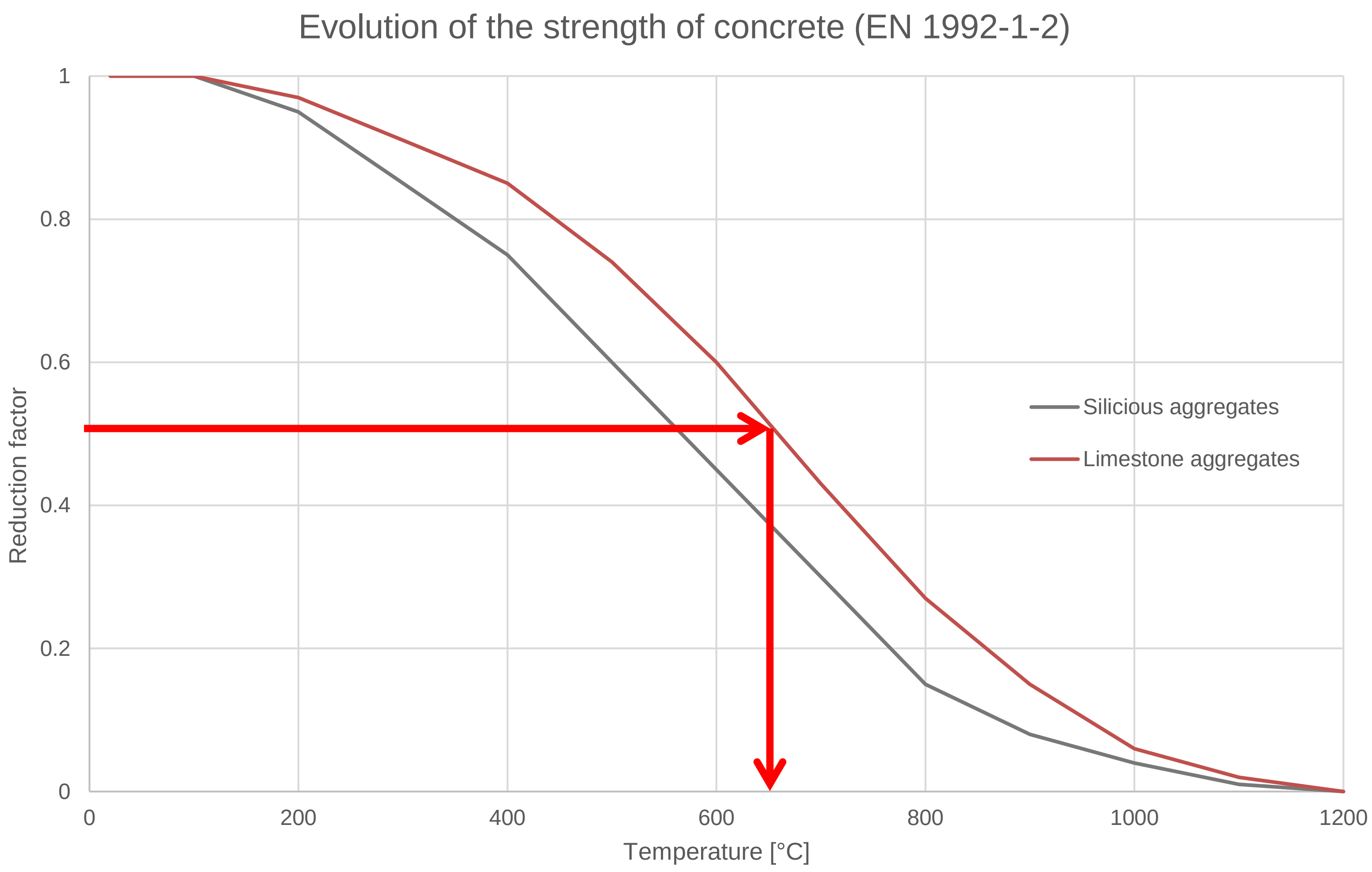


For steel :

50 % resistance losses at ~ 590 °C

Mechanical behaviour

Mechanical properties of concrete – EN 1992-1-2



For concrete (Limestone aggregates) :

50 % resistance losses at ~ 650 °C

Analysis

Natural fire analysis

Description of the calculation methods

For the analysis of this structure, we used a 3-dimensional model that corresponds to the substructure considered. This substructure is identical to that considered for "cold" design.

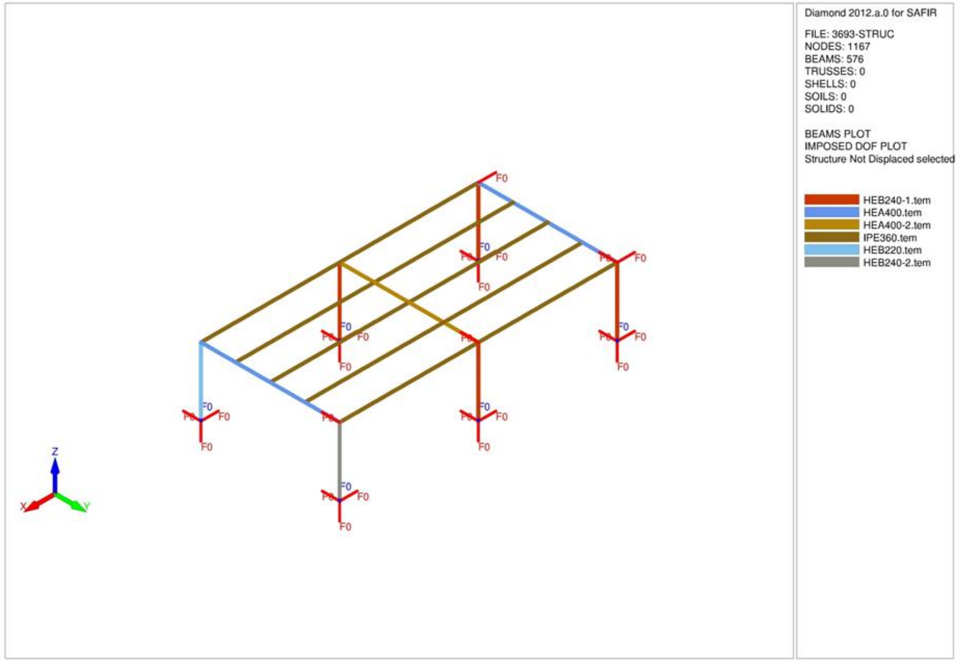
To prove the strength of the structural elements, finite element calculations with the SAFIR 2013 software were carried out according to the following scenario:

Natural fire analysis

Description of the calculation methods

For the analysis of this structure, we used a 3-dimensional model that corresponds to the substructure considered. This substructure is identical to that considered for "cold" design.

To prove the strength of the structural elements, finite element calculations with the SAFIR 2013 software were carried out according to the following scenario:



Natural fire analysis

Each straight section is subjected to the heating of the fire (natural or ISO): the heating of the sections is also determined.

A model comprising the different sections will be created and loaded with the accidental combination: the structural behavior is introduced.

The software calculates the statics at each time t and determines whether resistance is ensured at each temperature rise.

If the ruin takes place, the precise moment is known, so that its resistance can be determined.

If the ruin does not take place, we check that the deformations of the elements are acceptable.

Natural fire analysis

To take into account the importance of the vertical elements (columns), which support the rest of the BI building, we therefore also checked them under an ISO fire, which is more severe than natural fire - thermal action in our case.

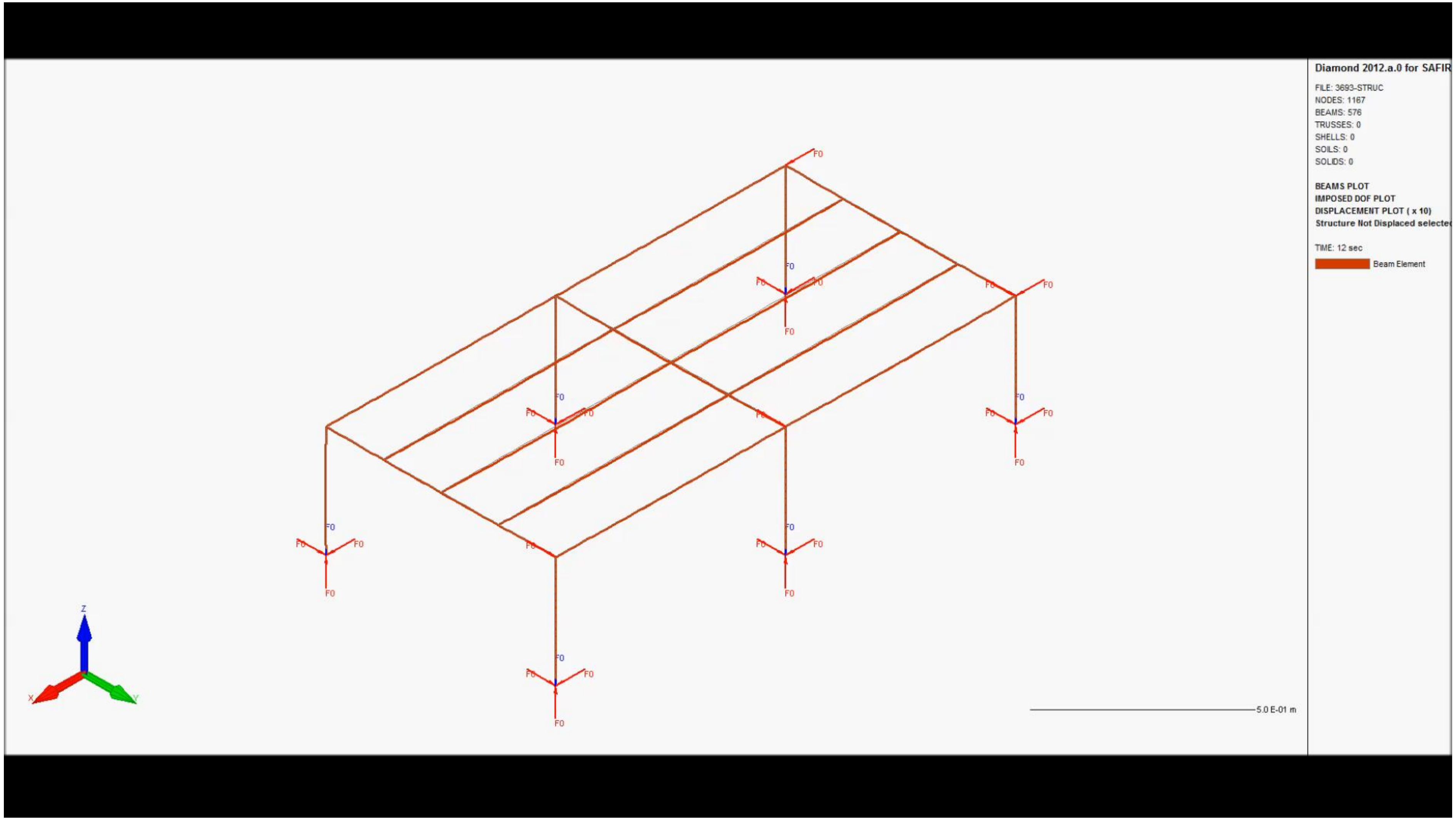
Indeed, there is not yet a general model for lights located in the right of a column. Research is currently underway.

The LOCAFI report on this method was published in 2017.

This research has shown that the action of a fire near a column is essentially due to radiation and the position of the column in relation to the focus.

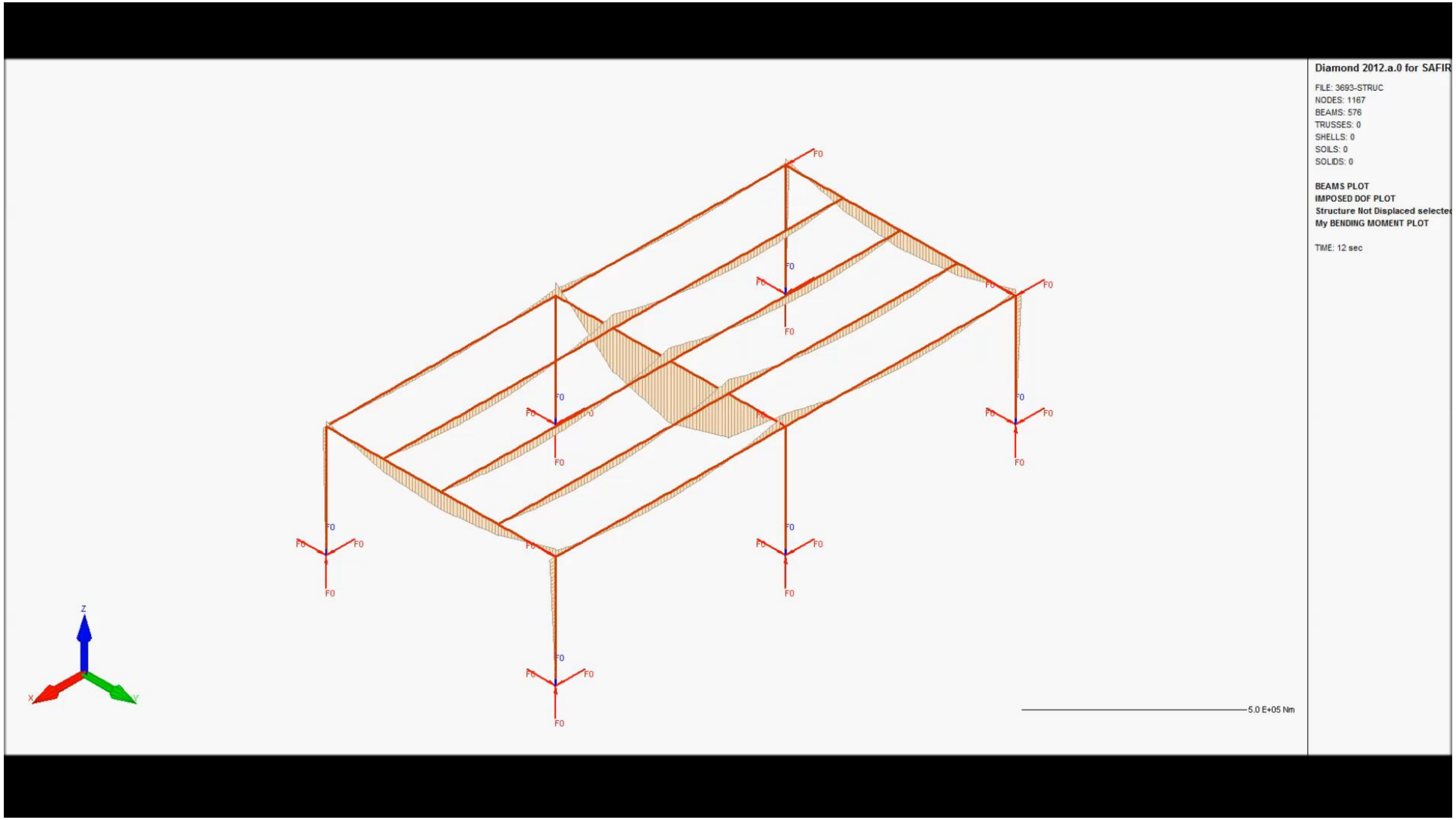
This method allows columns to be sized according to the thermal load of the compartment.

Natural fire analysis



Evolution of the deformation of the structure (factor 10x)

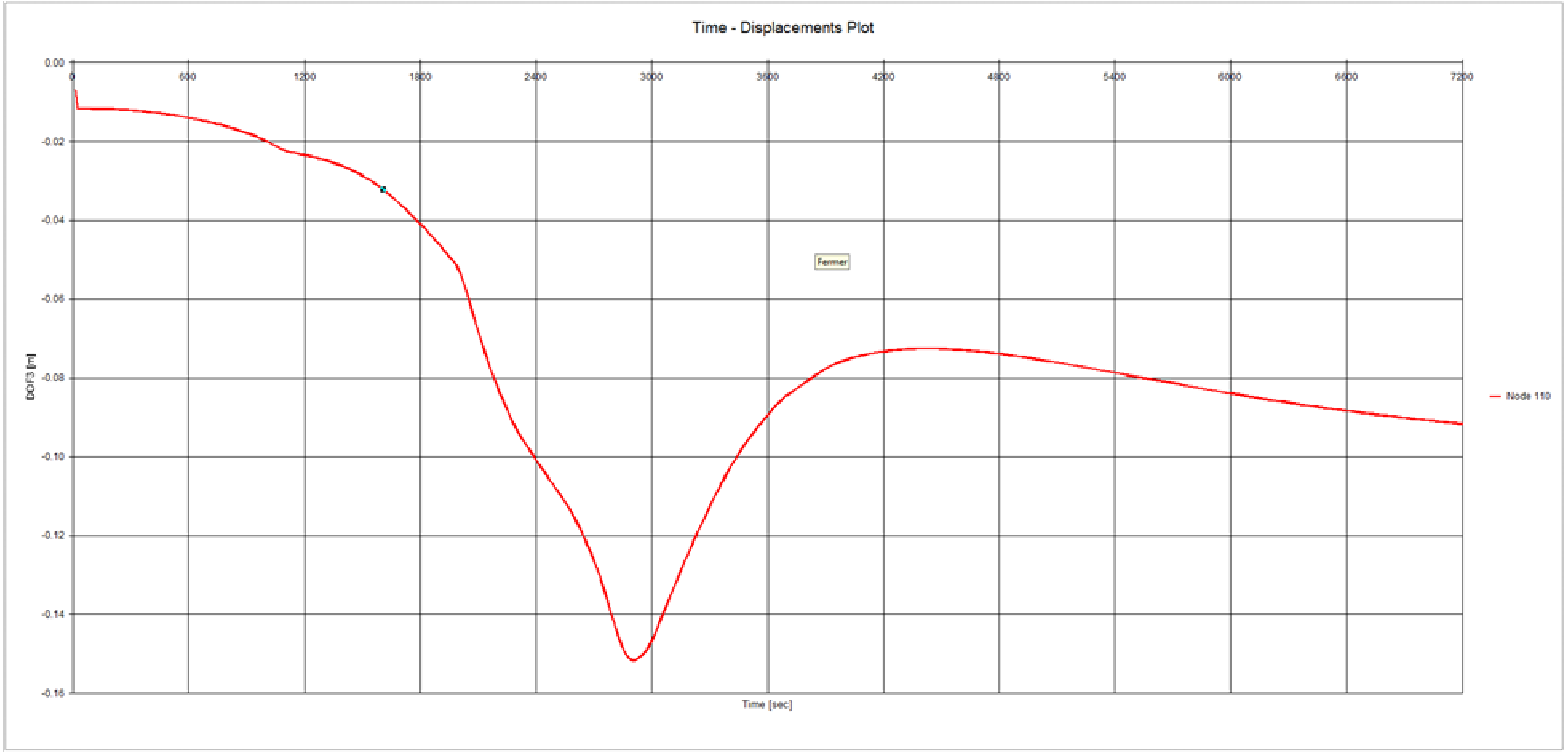
Natural fire analysis



Evolution of bending moments My (factor 10x)

Natural fire analysis

It can be seen that there is no asymptote on the curve of the deformation, for example the vertical deformation of node 110 located in the middle of an IPE 360 beam. The maximum value of the deformation is 15 cm, i.e. l/48, which is acceptable because it is above the limit of l/30 obtained following various tests carried out on this type of structure.



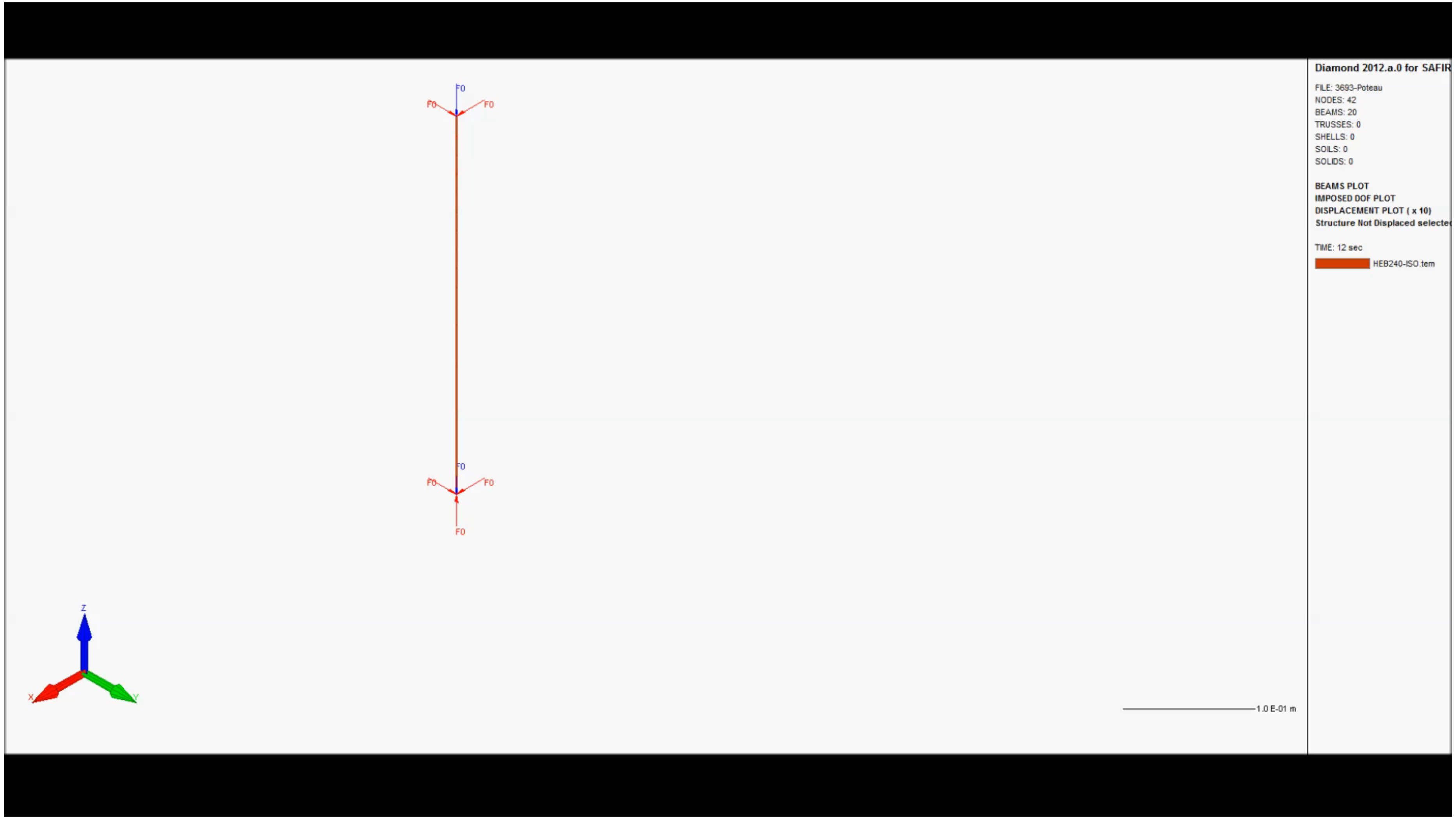
ISO Fire - analysis

ISO Fire Column Behavior

The columns supporting the BI building in the restaurant are made of box-box H-profiles.

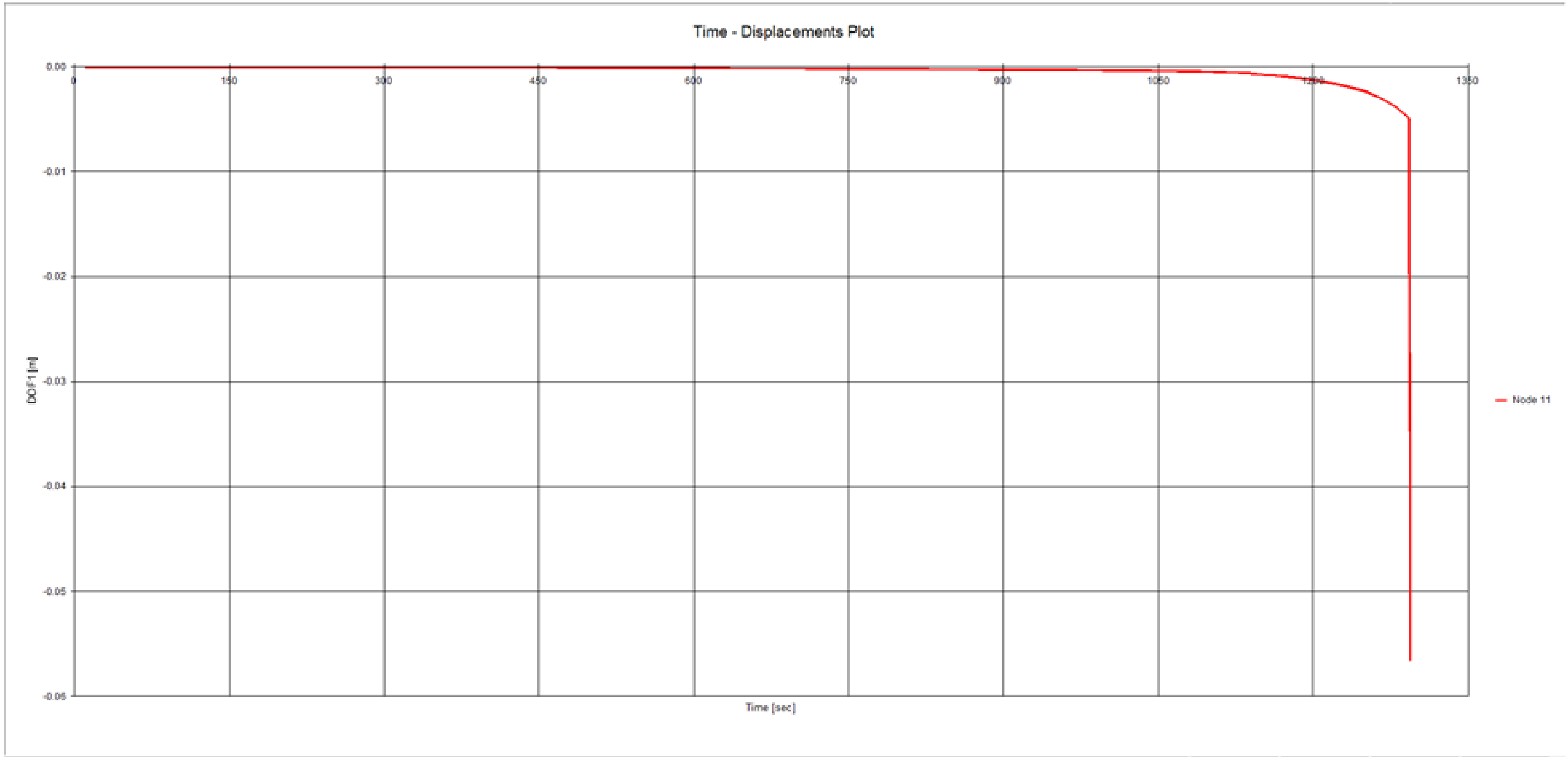
We studied the critical pole (the most loaded) which is composed of HEB 240 boxed with two 220/10 steel plates.

Fire ISO - analysis



Evolution of the deformation of the structure (factor 10x)

ISO Fire - analysis



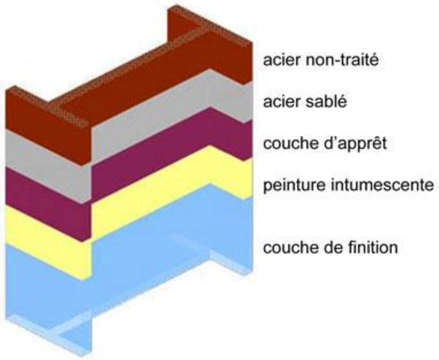
We notice that the HEB 240 column reaches its ruin at 1290 s, or a little more than 21 minutes.

Natural fire analysis

Conclusion of our case

- No protection on the floor beams subject to the action of natural fire - thermal action. The deformations will be significant, but the stability of the building is safeguarded. The project owner has validated this solution, which will involve the reconstruction of the floor in the event of a severe fire.

- Protection of the columns by intumescent paint (in order with the risk of impact in the context of this assignment) because essential elements for the safety of the building.



Examples

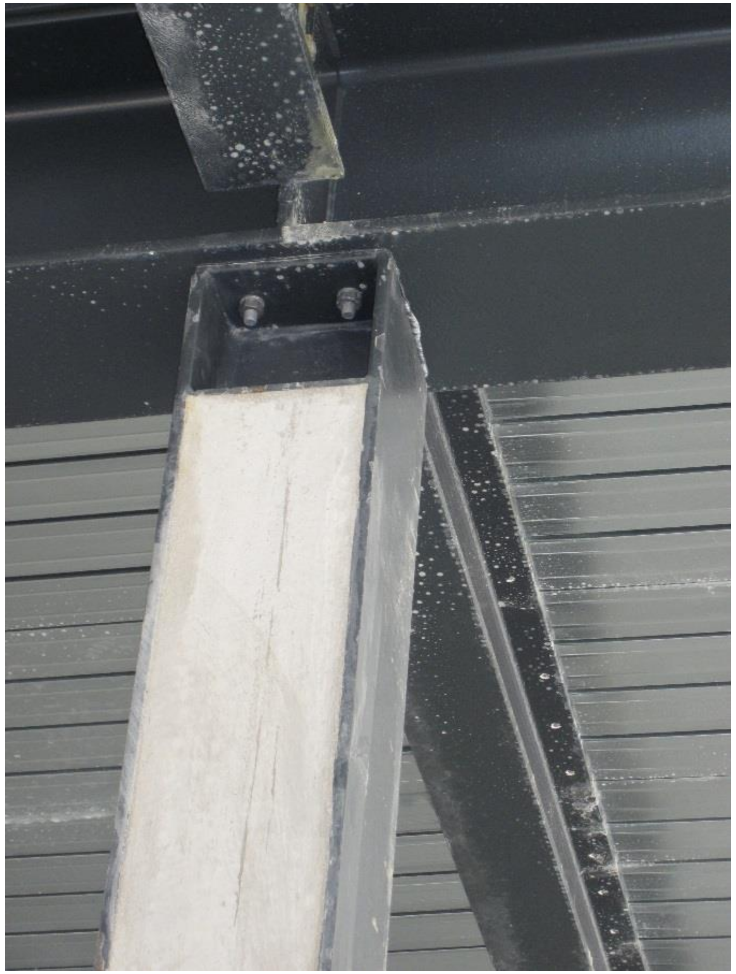
Examples

Shopping centre in Collombey

Examples

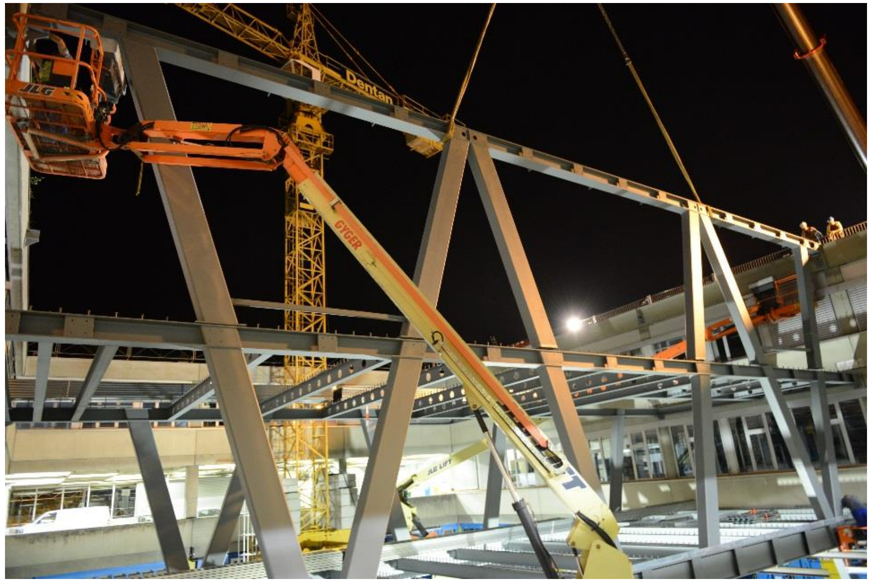
Multi-activity halls in Puidoux

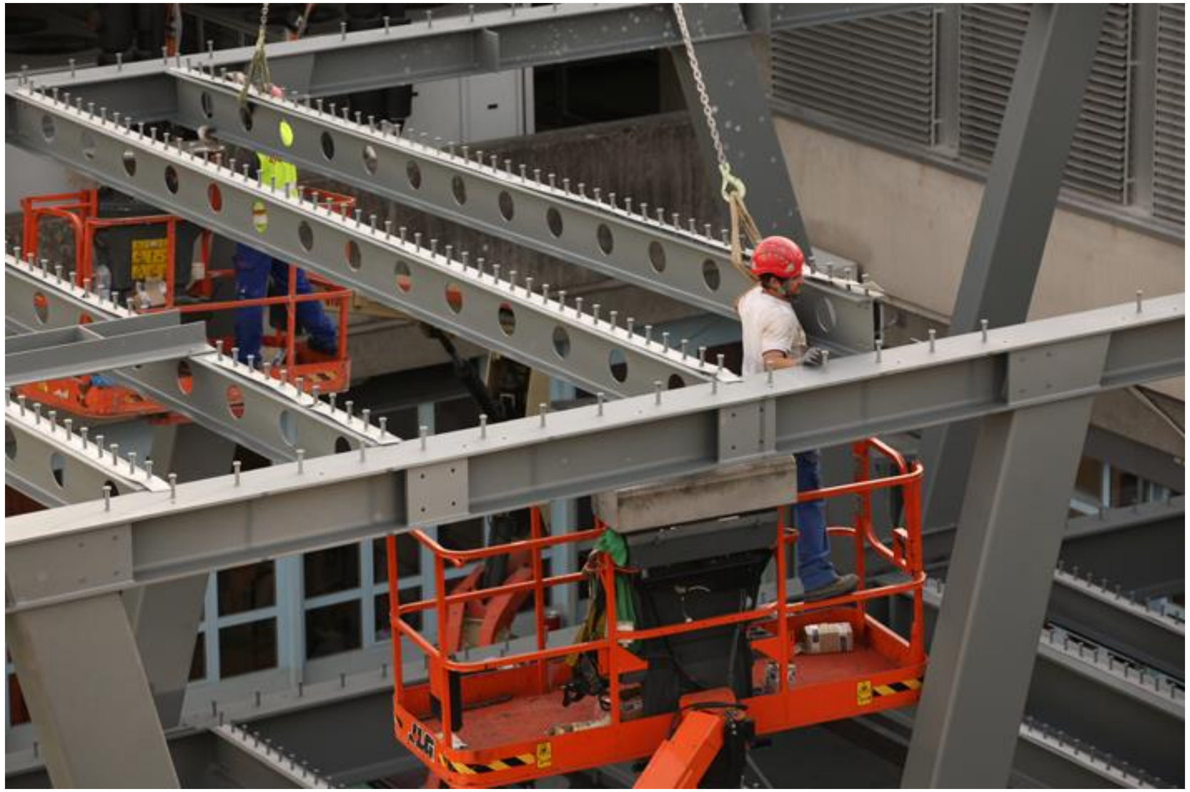
Examples



Multi-activity halls in Puidoux

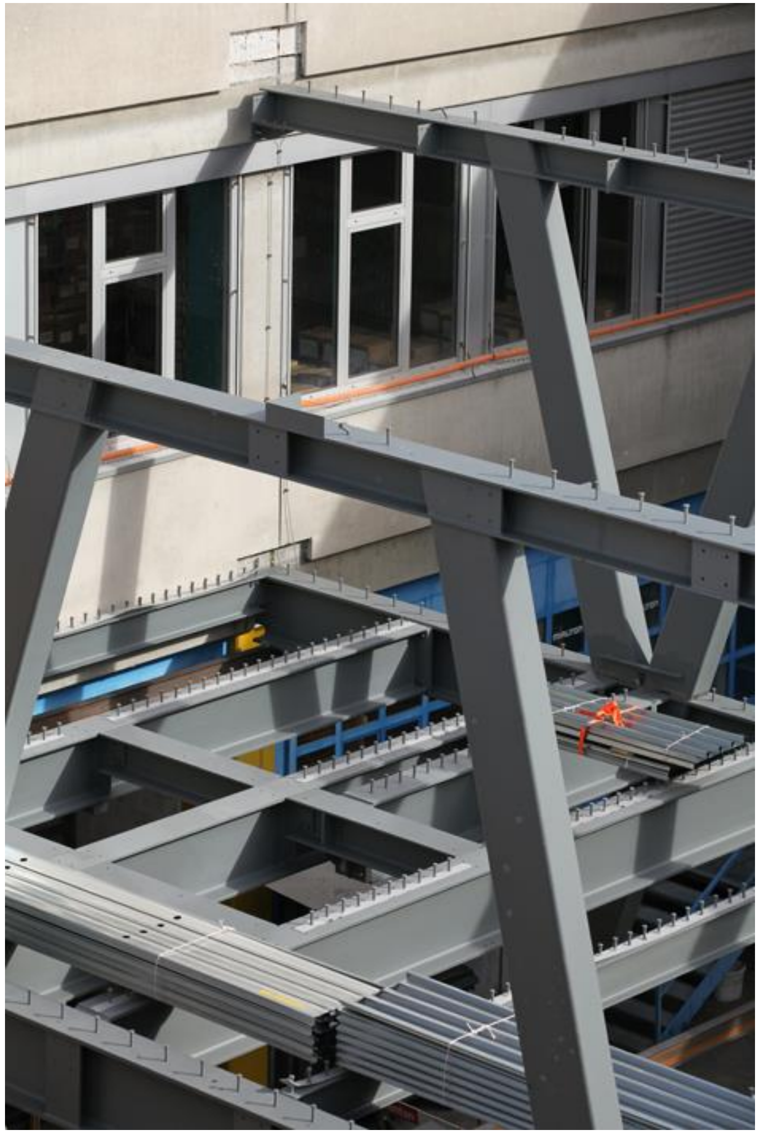
Examples

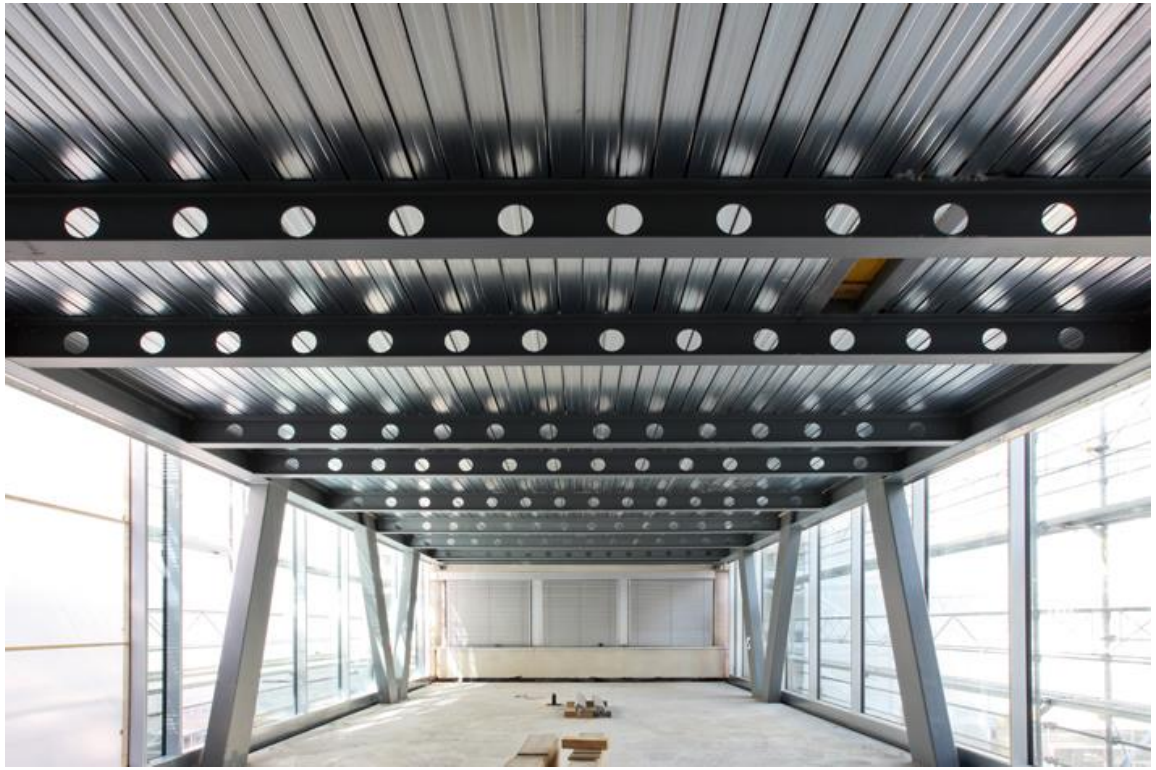




Connecting bridge (23m) in Lausanne

Examples

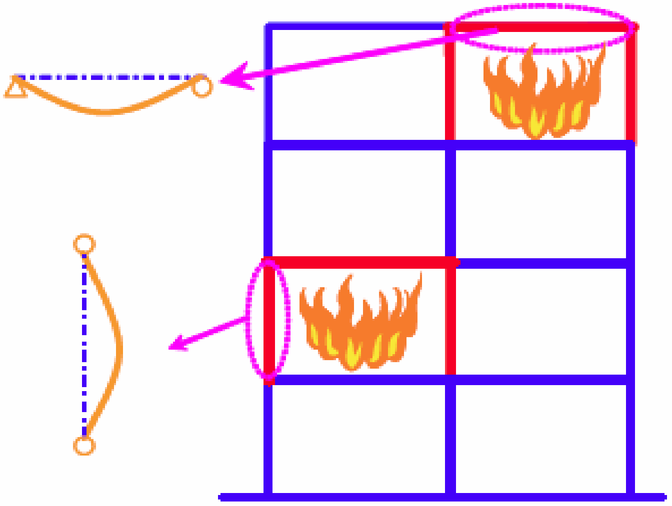
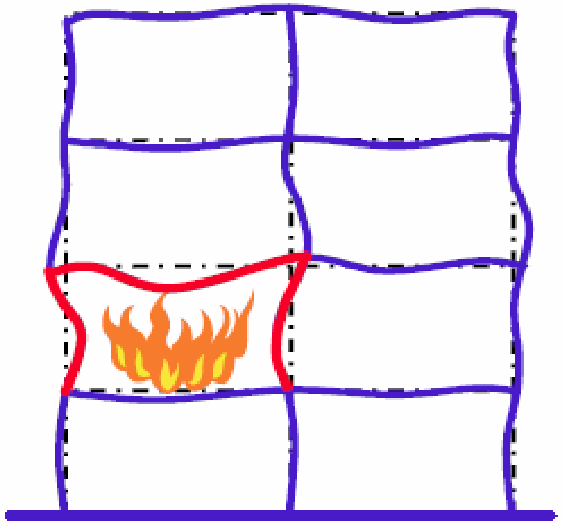




Connecting bridge (23m) in Lausanne

Conclusions

Conclusions

Local analysis	Global analysis
	
• Independant analysis of each element • Easy to apply • Generally used with normalized fire	• Interaction effects between parts of the structure • Compartimentation role • Global stability

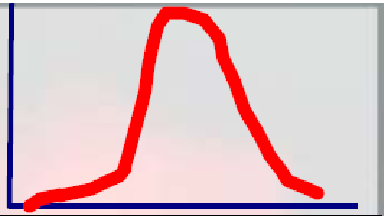
Conclusions

- Thermal action under normalized fire

Analysis type	Tabulated value	Simplified calculation models	Advanced calculation models
Analysis per element	Yes Normalized fire ISO-834	Yes	Yes
Partial analysis of the structure	Non applicable	Yes (if available)	Yes
Global analysis of the structure	Non applicable	Non applicable	Yes

Conclusions

- Thermal action under natural fire



Analysis type	Tabulated value	Simplified calculation models	Advanced calculation models
Analysis per element	Non applicable	Yes (if available)	Yes
Partial analysis of the structure	Non applicable	Non applicable	Yes
Global analysis of the structure	Non applicable	Non applicable	Yes

Conclusions

"Advanced" calculation and natural fire scenarios

Data

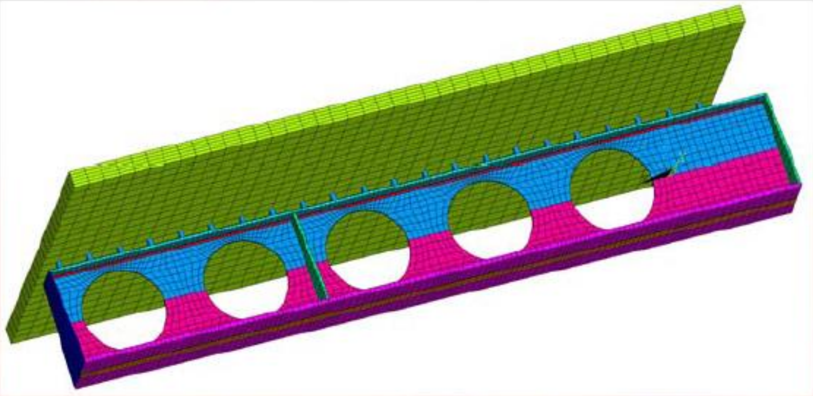
- Exact geometry of compartments, incl. windows
- Effective heat loads of compartments
- Technical and organisational measures

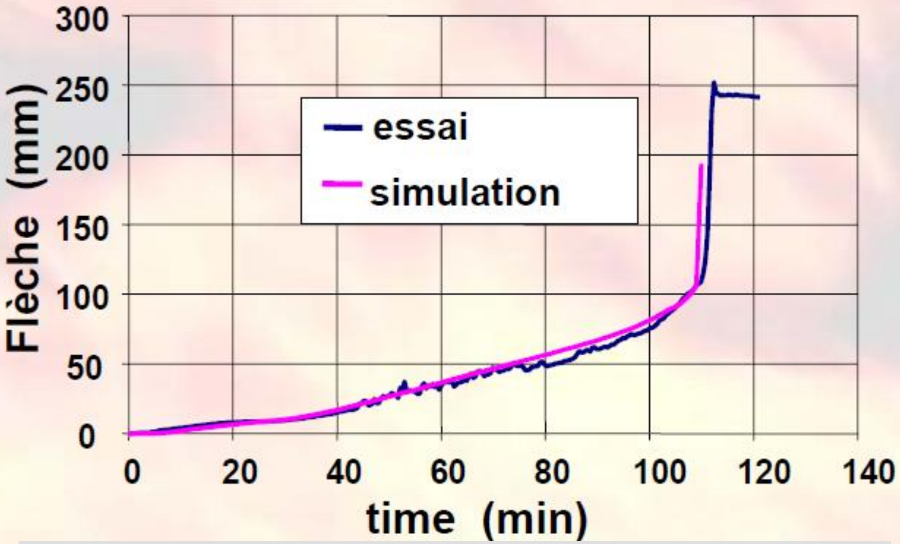
Analysis

- Scenario generation by varying variables (heat load, openings, detection systems)
- Reflection on scenarios, correcting data
- Eliminating implausible scenarios

Conclusions

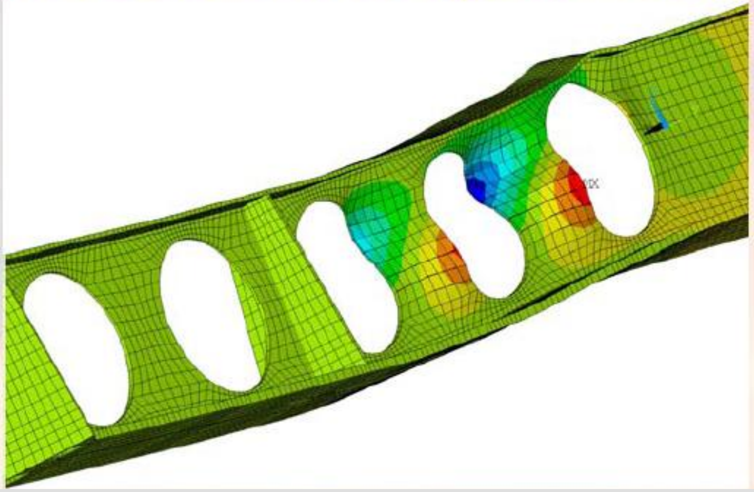
Advanced Calculations – EF 3D shell Models + Testing





Comparizon Test/Simulation

Experimental ruin model



Simulated ruin model

Conclusions

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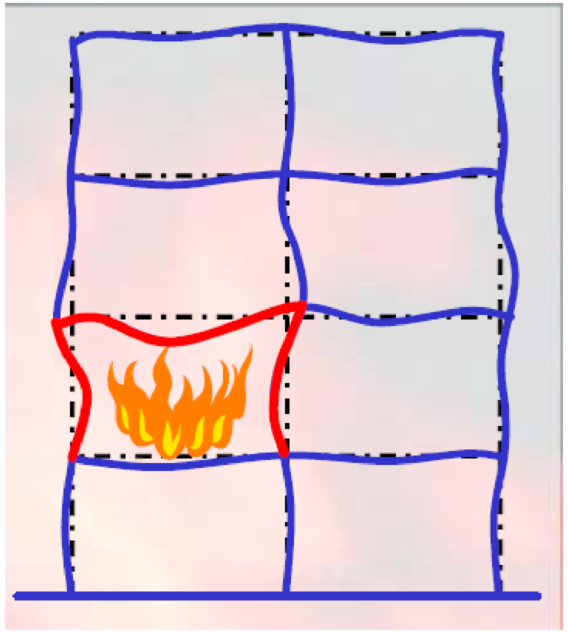
Advanced Calculation – General Rules

- Requires the use of advanced computational models
- Choosing the appropriate modeling of the structure
- Existing boundary conditions
- Loading conditions
- Suitable material models
- Boundary conditions in relation to the non-modelled part of the structure
- Analysis of results and verification of ruin criteria
- Review of aspects not covered in the direct analysis (consistency between numerical model and constructive details)

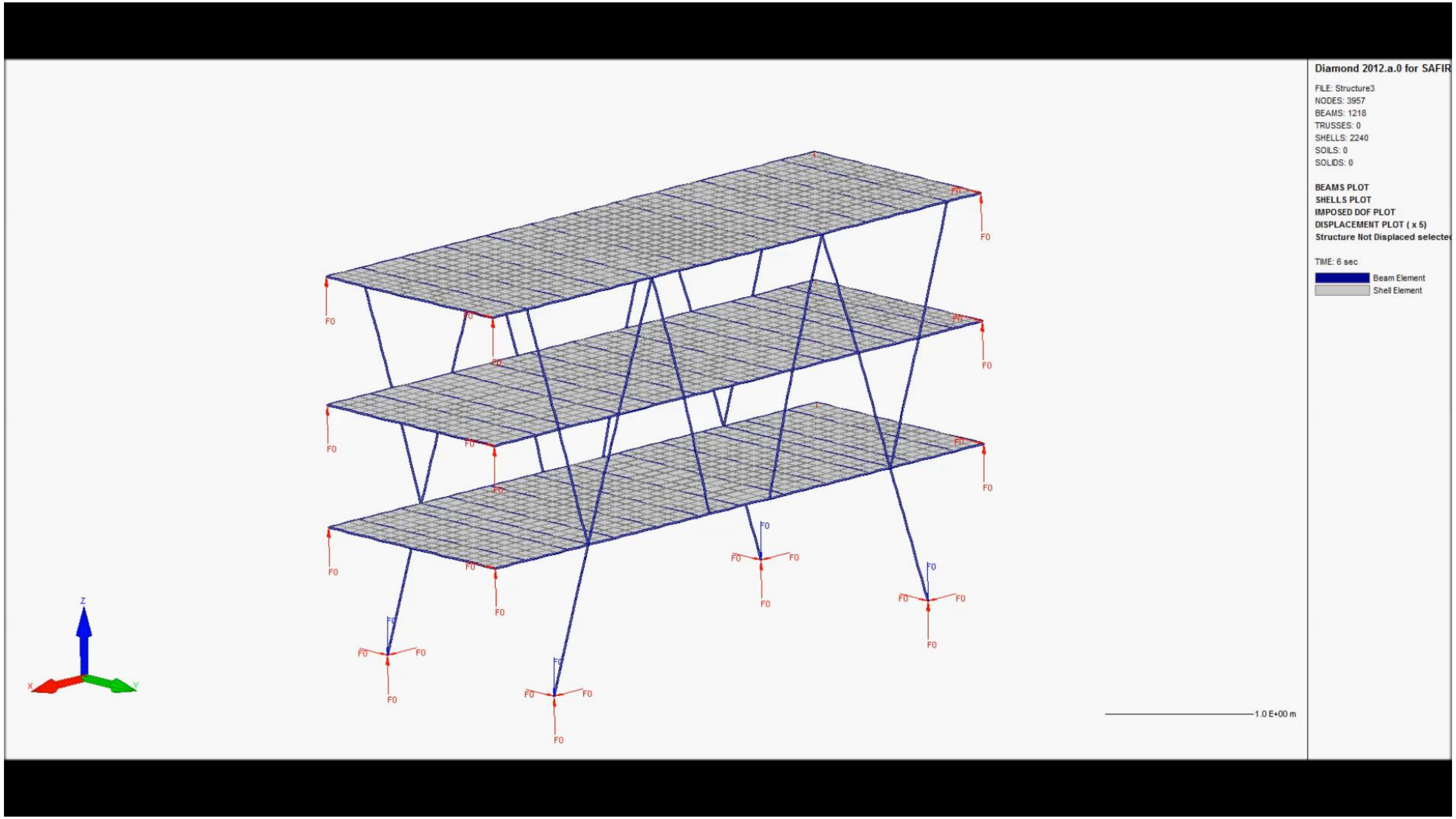


Conclusions

Advanced Models - CFDs

Conclusions

Advanced Templates - Safir



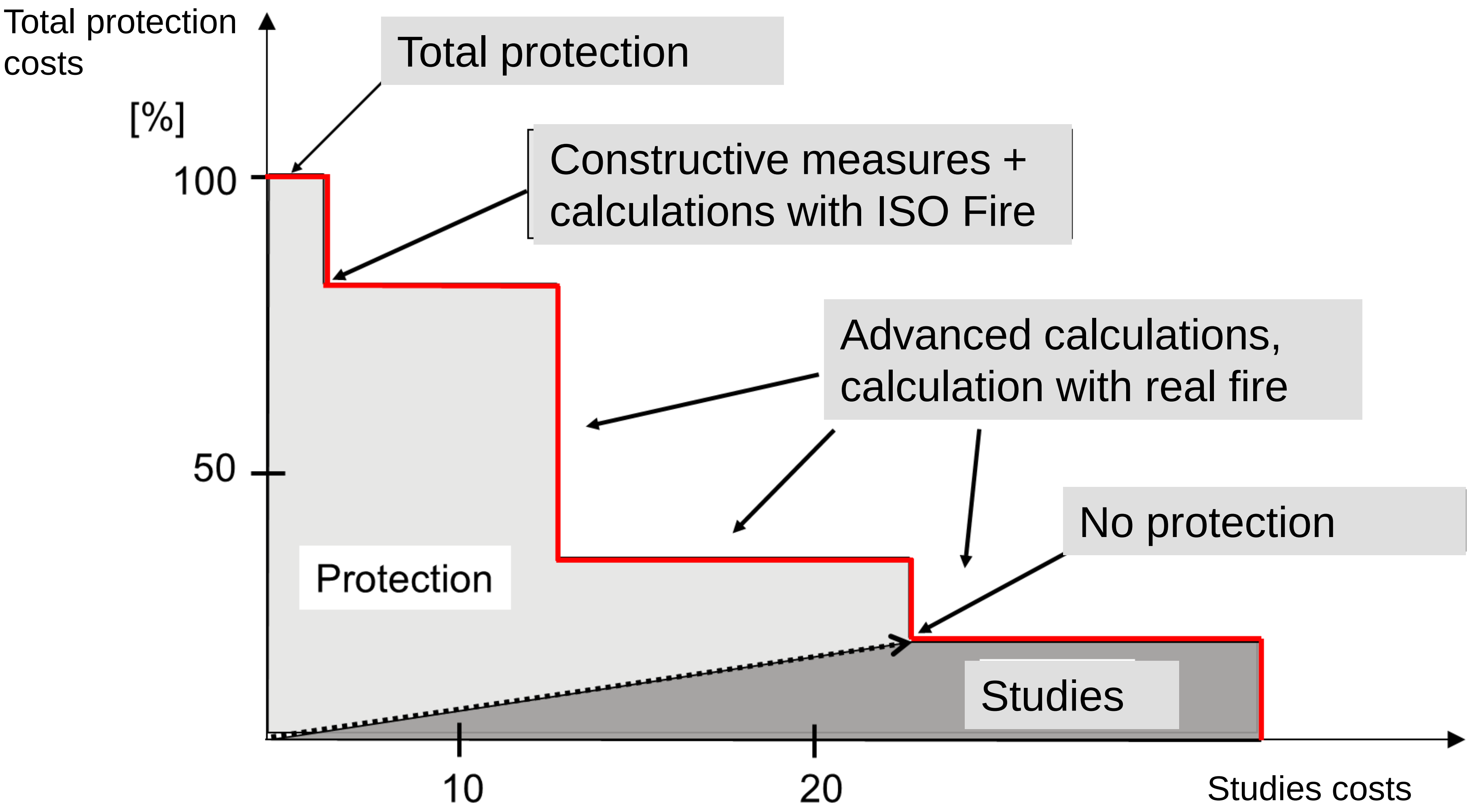
Conclusions

Fire Safety – Economical Analysis

Simplified calculations Standard concept	Advanced calculations Concept by structure
• Small works • Some isolated elements (beams, columns) • R 30 / R 60 • Study cost: low • Protection cost: up to 100% of the cost of the structure!	• "Important" works • Compliance • We can prove Rinfinite • Study cost: 5 to 20% of total protection • Cost of protection: 0 to 50% of total protection

Conclusions

Is fire engineering "profitable"?



Conclusions

In short

- Fire resistance is not an obstacle to steel construction or **to renovation!**

- Means and methods (simple or advanced) exist to verify and/or prove the resistance of the elements

- In many cases with a low thermal load (homes, offices), **Protection can be avoided!**

- Very complex field:

  Specialized engineer = **Savings** for the project!

Bibliography and sources

STANDARDS

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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

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

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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

WEBSITES
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SZS : www.szs.ch
LIGNUM : www.lignum.ch
ACCESS STEEL guides et exemples de calcul http://www.access-steel.com/
ECCS *European Convention for Constructional Steelwork (ECCS)* *http://www.steelconstruct.com*
DIFISEK : *Dissemination of Fire Safety Engineering Knowledge*
https://www.cticm.com/content/difisek-ingenierie-securite-incendie
SECURE WITH STEEL
http://sections.arcelormittal.com/network/partnerships/fire-safety-engineering.html
NIST : *Building and Fire Research Laboratory's Fire Research Division at NIST*
http://www.fire.nist.gov/

ANY QUESTIONS?

Thank you for your attention

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