EPFL

RESSLab

Fire Safety & Engineering SA

Fire Protection Engineering

Introductory Course – Part 2

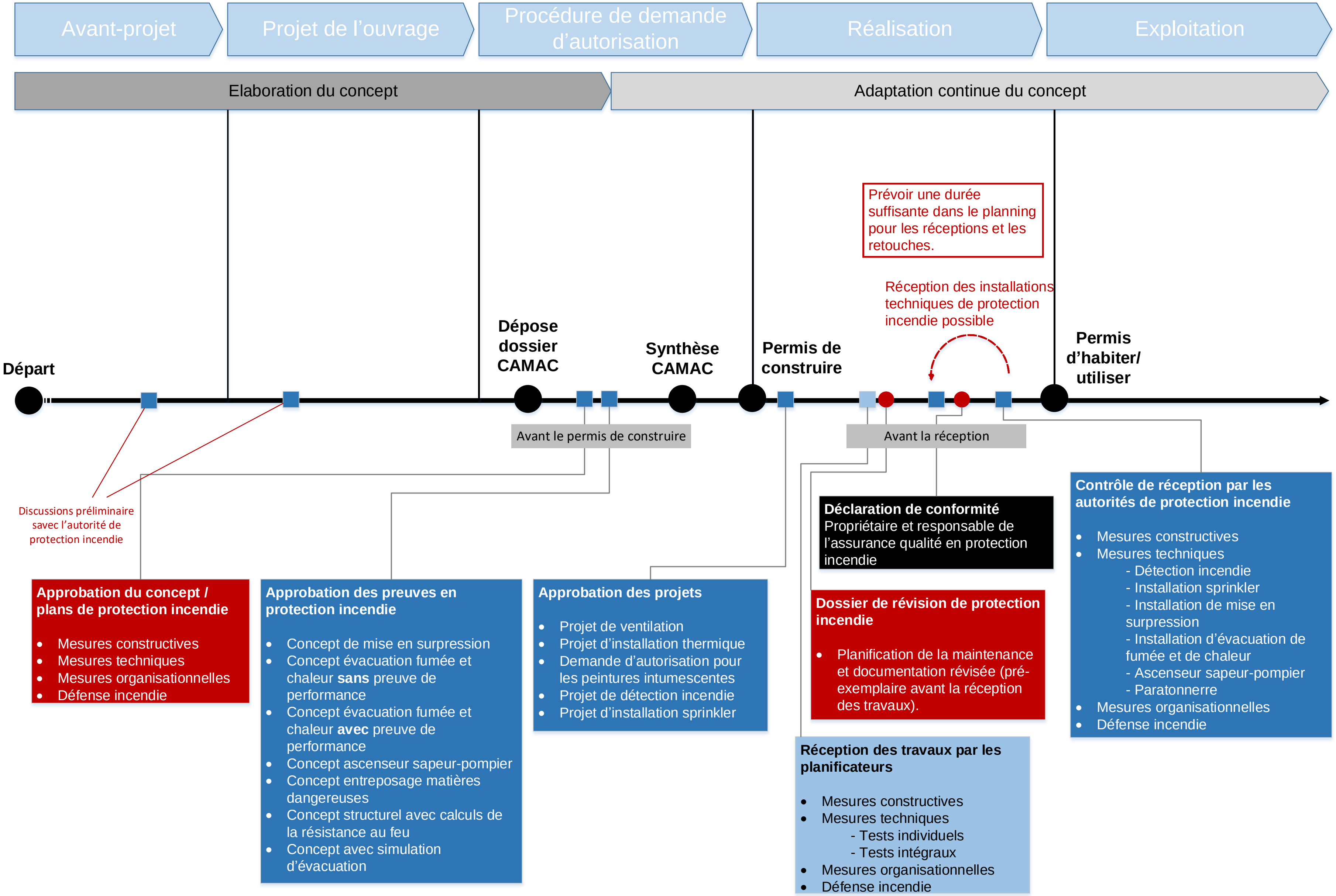
Olivier Burnier, civil engineer HES-UTS
Fire protection expert with federal diploma

Summary

- General organisation of fire protection, AEAI 2015 prescription
- DPI 11-15 Quality Assurance in Fire Protection
- DPI 27-15 Method of Evidence in Fire Protection
- DPI 13-15 Materials and Components of Construction
- DPI 14-15 Use of Building Materials
- DPI 15-15 Fire safety distances, load-bearing systems and fire compartments
- DPI 19-15 Sprinkler systems
- DPI 20-15 Fire Detection Installations
- Fire resistance of composite floors
- Membrane action of composite structures in case of Fire (MACS+)
- Temperature assessment of a vertical steel member subjected to localized fire

General organisation of fire protection, AEAI 2015 prescription

Project Process



Project Process

Basis for a fire protection concept

Fire protection

Prevention

Intervention

Constructive measures

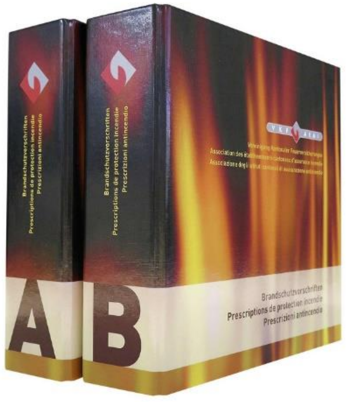
Technical measures

Organizational measures

The 1-15 fire protection standard

Some important articles of the AEAI standard

Article 1 – Purpose



- The fire protection regulations are intended to protect people, animals and property from the dangers and effects of fires and explosions.
- They set out the legal obligations necessary to achieve this goal.

The 1-15 fire protection standard

Fire Safety & Engineering SA

Some important articles of the AEAI standard

Article 2 – Application field

The protection requirements apply to buildings and other structures to be constructed and, by analogy, to movable constructions.

Existing buildings and other structures will be brought into compliance with the requirements according to a principle of proportionality.

a. In the event of a major conversion, extension or change of use of the construction or holding.

b. When the danger is particularly great for people.

The 1-15 fire protection standard

Some important articles of the AEAI standard

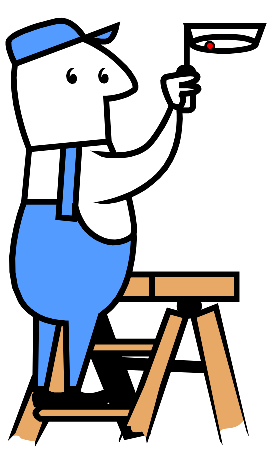
Article 3 – Who is concerned

The fire protection regulations concern:

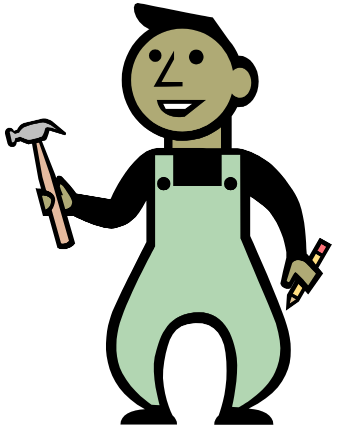
a. Owners and operators of buildings and other structures.

b. All the people who are involved in their design, construction, operation or maintenance.

Architect



Engineer



Specialist CVSE

The 1-15 fire protection standard

Some important articles of the AEAI standard

Article 8 – Protection objectives

Buildings and other structures must be constructed, operated and maintained in a manner that:

a) To guarantee the safety of people and animals.
b) Prevent fires, explosions and limit the spread of flames, heat and smoke.
c) Limit the risk of fire spreading to neighbouring buildings and structures.
d) Maintain the structural stability of buildings and other structures for a specified period of time.
e) To enable effective firefighting and to guarantee the safety of firefighters.

The 1-15 fire protection standard

Some important articles of the AEAI standard

Article 9 – Criteria for determining requirements

Fire protection requirements in buildings and other structures are determined by:

a) The type of construction, the location, the risks in relation to the neighbourhood, the extent and the use.
b) The geometry of the building and the number of levels.
c) The number of occupants.
d) The heat load and reaction to fire of the materials as well as the danger of smoke development.
e) The danger of activation inherent in the use of the building or structure and the activities that take place there.
f) The possibilities of intervention of the fire brigade.

The 1-15 fire protection standard

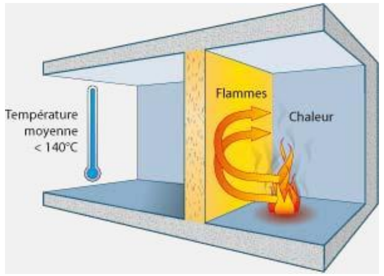
Some important articles of the AEAI standard

Article 10 – Standard fire protection concept

In the standard fire protection concept, the protection objectives are achieved in accordance with the prescribed measures.

«Construction» concept

The fire protection concept based on building measures makes it possible to achieve the protection objectives through construction measures. It may be necessary to include additional fire protection equipment, depending on the use of the building or structure in question.



«Extinction installation» concept

The fire protection concept with extinguishing system integrates fixed extinguishing systems recognised by the AEAI into the fire protection measures relating to construction.

The 1-15 fire protection standard

Some important articles of the AEAI standard

Article 11 – Deviation from the standard concept

Within the framework of standard concepts, it is possible to apply other fire protection measures on a case-by-case basis instead of the prescribed measures, provided that these provide equivalent safety for the object in question. The fire protection authority shall decide on this equivalence.

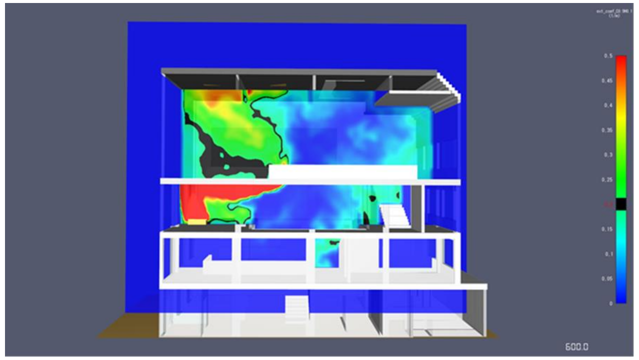
If, in a particular case, the fire danger deviates so much from the standard concept that the prescribed requirements prove to be insufficient or disproportionate, the measures to be taken will be supplemented or reduced accordingly.

The 1-15 fire protection standard

Some important articles of the AEAI standard

Article 12 – Methods of evidence

In fire protection, it is permissible to use methods of evidence to assess the danger and risk of fire, or the concepts on which fire safety is based in a particular case, provided that the objectives defined in the fire protection standard are achieved and the problem is considered as a whole.



The fire protection authority examines fire protection concepts and evidence to ensure that they are complete, comprehensible and plausible.

The 1-15 fire protection standard

Some important articles of the AEAI standard

Article 13 – Definitions

Accommodation establishments

- [a] in particular hospitals, retirement homes, nursing homes where 20 or more people in need of help from third parties are staying permanently or temporarily.
-
- [b] in particular hotels, pensions, holiday resorts where 20 or more people are staying, permanently or temporarily, without the help of third parties.
-
- [c] In particular, isolated accommodation establishments with access restrictions, accommodating 20 or more people, exclusively hikers.

The 1-15 fire protection standard

Some important articles of the AEAI standard

Article 13 – Definitions

Stores and Warehouses

- Warehouses with a total surface area of more than 1,200 m^2 per fire compartment.

Places receiving a large number of people

- Premises with a capacity of more than 300 people, including multi-purpose halls, sports halls and exhibition halls, theatres, cinemas, restaurants and similar premises, as well as shops with a sales area of up to 1,200 m^2.

The 1-15 fire protection standard

Some important articles of the AEAI standard

Article 13 – Definitions

Parkings

- Parkings with a surface area of more than 600 m^2.

High-bay warehouses

- Racked warehouses in which aisles are set up and whose height, measured from the floor to the top of the goods on the highest shelf, is more than 7.50 m.

Movable construction

- Buildings built for a limited period of time (such as barracks, containers, tents and marquees, huts and stalls).

The 1-15 fire protection standard

Definition of building height

Low-height buildings :

- Up to 11m
- Usually 1-3 levels

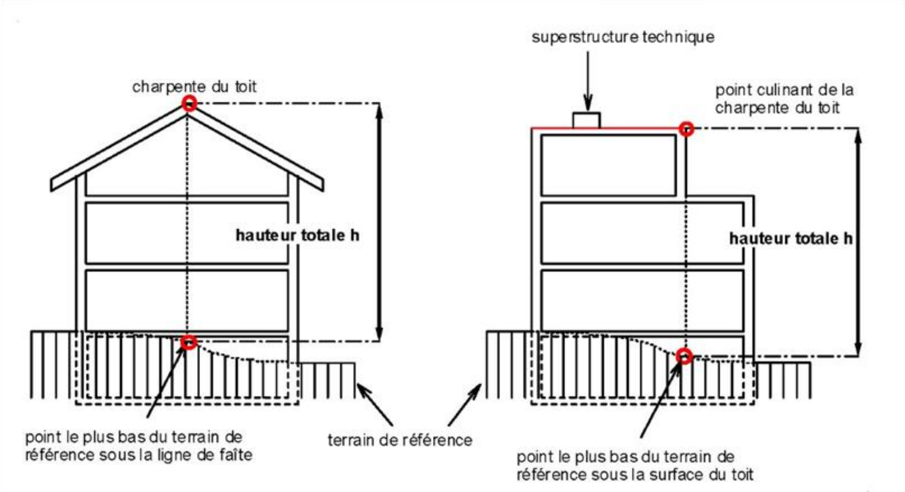
Mid-height buildings :

- 11-30m
- Usually 4-8 levels

High buildings :

- More than 30m
- Usually more than 9 levels

Measuring method according to AIHC



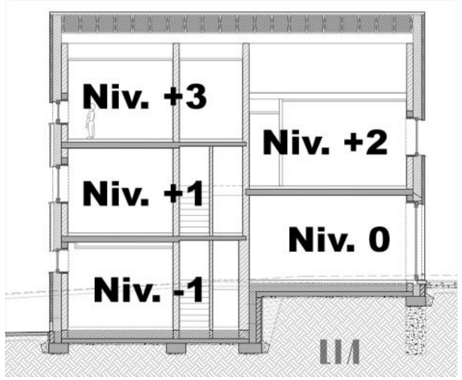
The 1-15 fire protection standard

Some important articles of the AEAI standard

Article 13 – Definitions

Number of levels

- All complete levels from the ground floor, the attic and the attic are considered for fire protection. Levels where the exterior walls are more than 50% below the level of the land are considered to be underground. Half-storeys that cover more than 50% of the building's floor area are considered full levels.



Materials and building elements subject to fire protection requirements

- Materials and components in accordance with the fire protection regulations correspond to the definition of a construction product according to Article 2, Bed 1 of the Federal Construction Products Act (No. 933.0). The same is true for equipment.

DPI 11-15 Quality Assurance in Fire Protection

Quality assurance in fire protection

What for?

- Society's demands on security have risen sharply in general: protection of the environment, against burglary, data, the fight against terrorism, etc.
- Users' expectations of quality have increased across the board.
- In construction, the planning and construction time is getting shorter and shorter.
- Customers very often demand the lowest costs and maximum returns.

Quality assurance in fire protection

Why in the construction industry?

How good is the planning and execution of fire protection measures in Switzerland today?

- Planning is often poorly coordinated and incomplete.
- No clear responsibilities between the parties involved, inaccurate or incomplete descriptions of the services to be performed.
- Little knowledge of fire protection by the various stakeholders.
- Unclear interfaces between the different trades.
- Forgotten or poorly executed details.
- The use of inappropriate products.

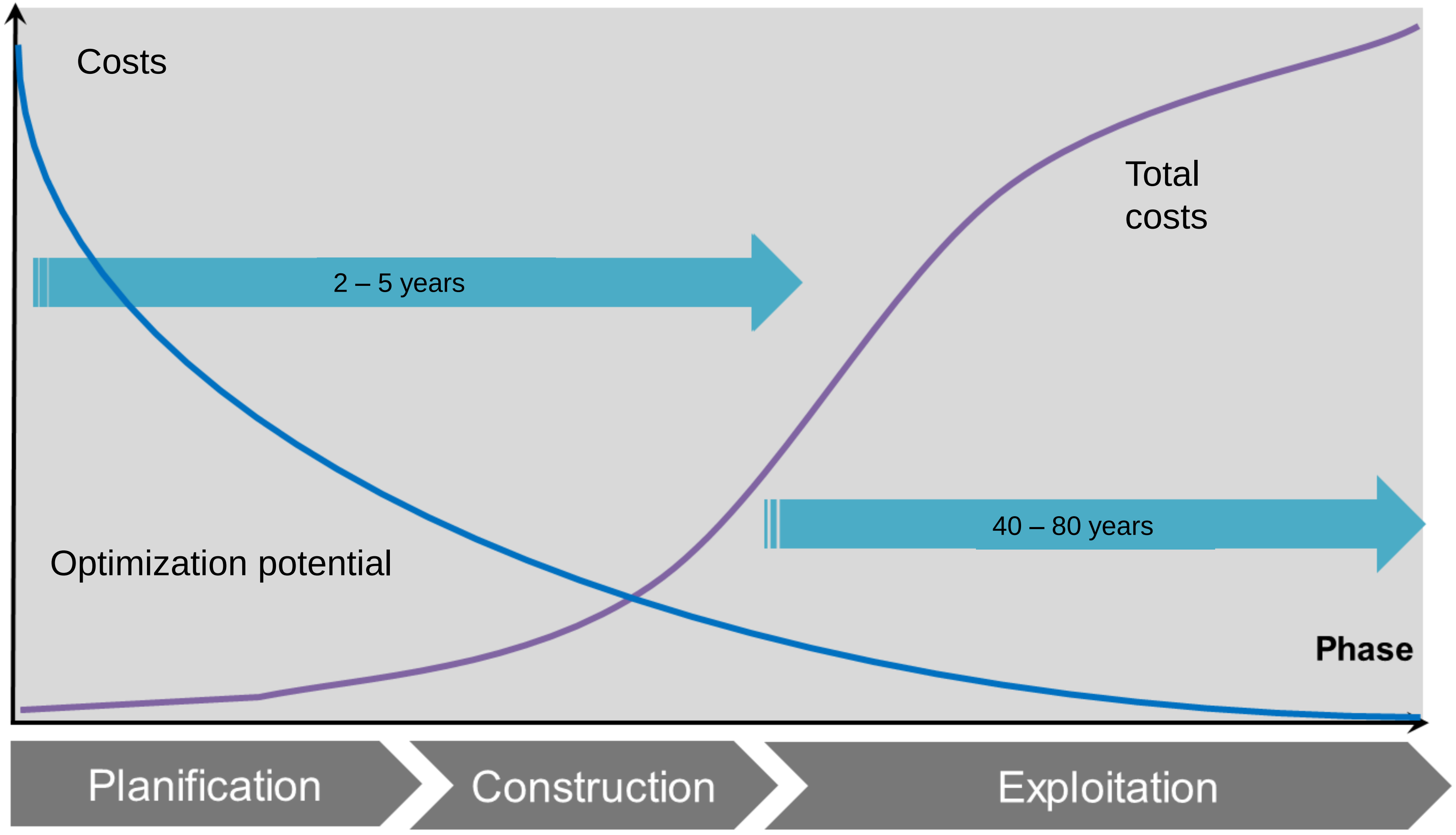
The phases of a fire protection project

General

- Fire protection measures apply to almost all areas of the building.
- To carry out a project in good conditions and with cost control, it is important to plan future constructions or conversions well.
- Significant capital gains can arise if fire protection measures are not integrated into the project as early as possible and continuously adapted to the development of the project.
- Quality assurance in fire protection ensures that constructive and technical fire protection measures are correctly implemented and that their operation is guaranteed throughout the life of the building.

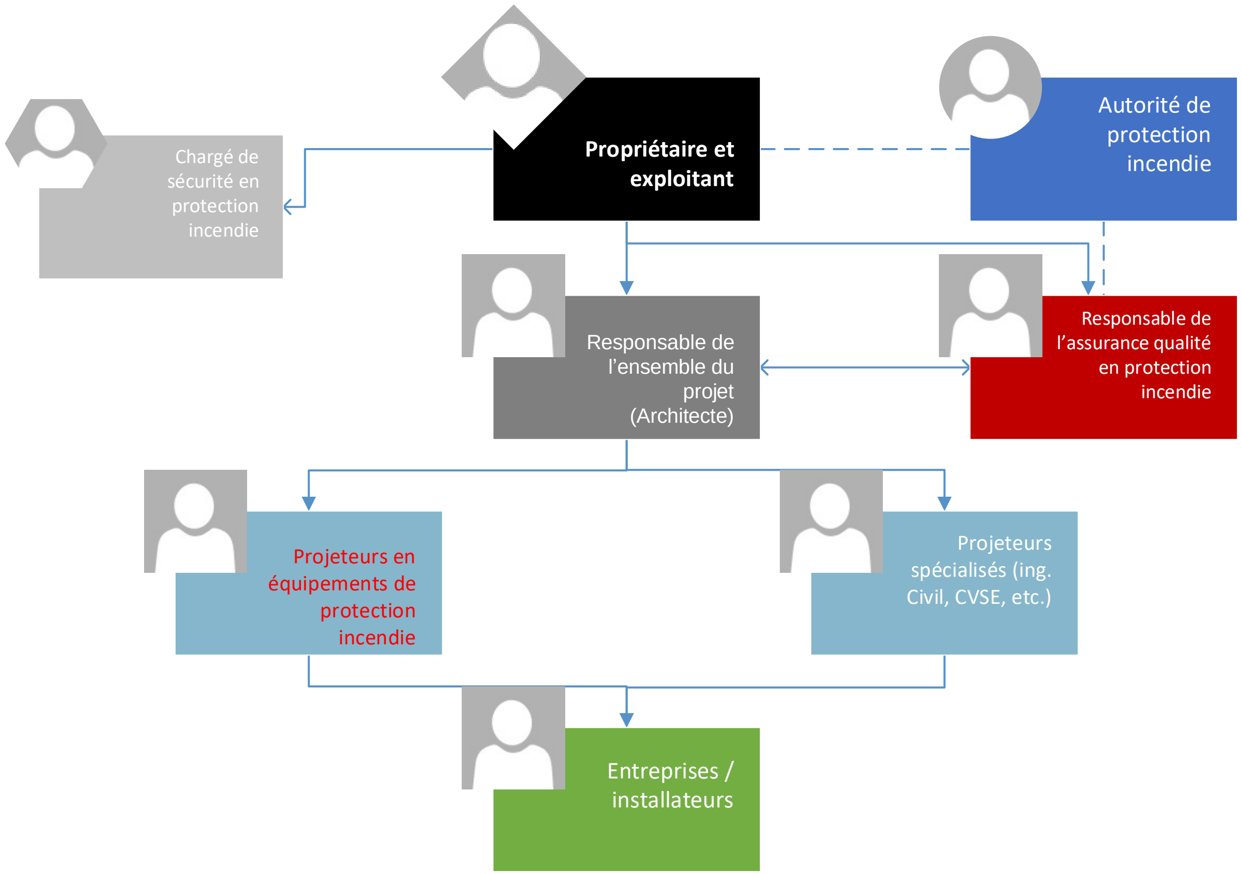
The phases of a fire protection project

Economic optimization in a global vision



The phases of a fire protection project

Project organization

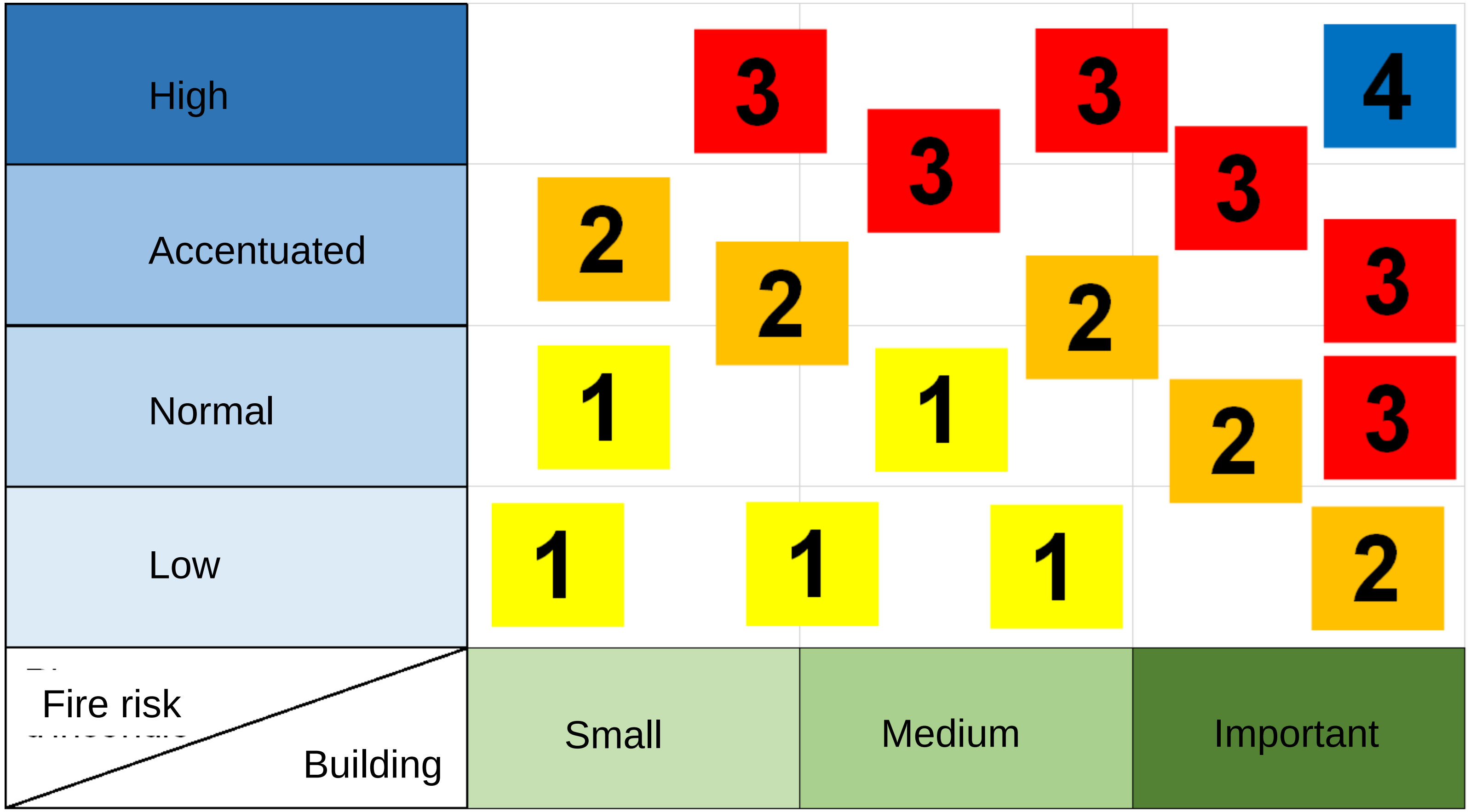


Contractual or professional subordinate relationships as well as possible information flows

Information Flow

Implementing Quality Assurance

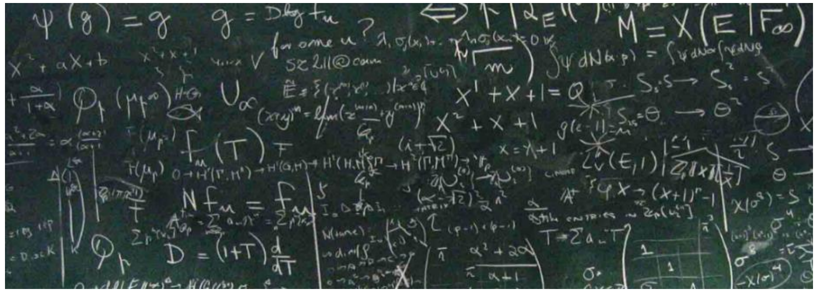
Principle of quality assurance in fire protection



DPI 27-15 Methods of Evidence in Fire Protection

DPI 27-15 – Method of evidence

- The use of evidentiary methods confers greater responsibility on the persons concerned, according to Article 3 of the Fire Protection Standard.
- The fire protection authority decides on the admissibility of fire protection proof methods and on the recognition of fire protection specialists. In this regard, the following principles apply:
  - Only methods that are recognized or considered equivalent may be used.
  - Fire protection concepts using evidentiary methods may only be presented by recognised or equivalent specialists.



DPI 27-15 – Method of evidence

Examination by the fire protection authority

- The fire protection authority examines fire protection concepts and evidence to ensure that they are complete, comprehensible and plausible.

Load-bearing system calculations

- Simplified calculation models and general calculation models based on Eurocodes (computational proofs / natural fire models) must be validated by a qualified engineer.

- Evidence based on a natural fire scenario should result in the same safety as that using standard fires. It is therefore necessary to provide for an adequate and recognised fire safety concept for construction measures

Fire Safety Engineering

SFPE Engineering Guide to Performance-Based Fire Protection

Fire engineers carrying out analyses and sizing must be qualified, through their training, practice and experience, and they must, in particular:

- Be competent in the application of scientific and engineering principles to assess the consequences of fire on the safety of people, buildings and property.
- Have a working knowledge of the nature and characteristics of fire and the hazards associated with it, including ignition, development and spread of fire.
- Understand the impact of a fire and its effluents on buildings, processes, facilities and people.
- Have skills in occupant and emergency responder behaviour.
- Practice engineering ethically.

DPI 13-15 Materials and Components of Construction

DPI – Materials and Building Elements

- Building materials
  - Building materials are all materials used in the construction and furnishing of buildings, structures and building elements that are subject to fire protection requirements.

    (Reaction to Fire Classification) = I.I or EN

- Building Elements
  - All parts of the structure that are subject to fire resistance requirements are considered to be structural elements.

    (fire resistance class) = REI

DPI – Materials and Building Elements

I-I
(18 cl.)

SN EN 13501-1
Building materials (40 cl.)
Flooring (11 cl.)
Thermal insulation product for linear pipes (40 cl.)

SN EN 13501-5
Roofs
(13 cl.)

SN EN 13501-6
Electrical Cables
(183 cl.)

Generally Recognized Building Materials

RF1	No contribution to fire
RF2	Low contribution to fire
RF2 (cr)	Low fire contribution with critical reaction
RF3	Allowable Fire Contribution
RF3 (cr)	Eligible Critical Response Contribution
RF4 (cr)	Ineligible Contribution to Fire with Critical Response

DPI – Materials and Building Elements

Catégorie de réaction au feu	Réaction critique	Classification AEAI (indice d'incendie)
RF1		6.,3 6q.3
RF2		5(200°C).3 5.3 5(200°C).2 5.2
	cr	5(200°C).1 5.1
RF3		4.3 4.2
	cr	4.1
RF4		3.3 3.2
	cr	3.1
Non admis comme maté-riau de construction		2.3 2.2 2.1 1.3 1.2 1.1

Indices d'incendie de divers matériaux de construction	
4.3	épicéa, sapin, hêtre, panneau aggloméré et panneau en fibres de bois, tendre ou dur
5.1	panneau de polystyrène expansé, barrière vapeur en PE souple
5.3	chêne, panneau aggloméré traité anti-feu, isolation fibres de cellulose, revêtement de sol en chêne, hêtre, frêne ou panneau dur en fibres
6q.3	panneau de fibres minérales, plaque de plâtre cartonné ou armé de fibres, panneau de copeaux agglomérés liés avec du plâtre ou du ciment
6	Acier, béton, brique terre cuite, verre

DPI 14-15 Use of Building Materials

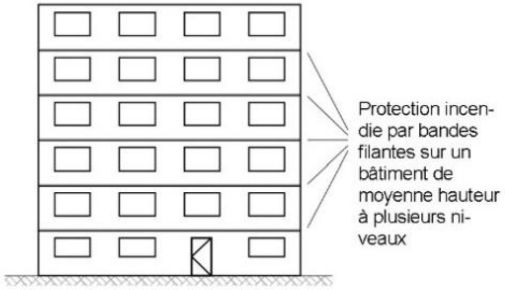
NPI - Example

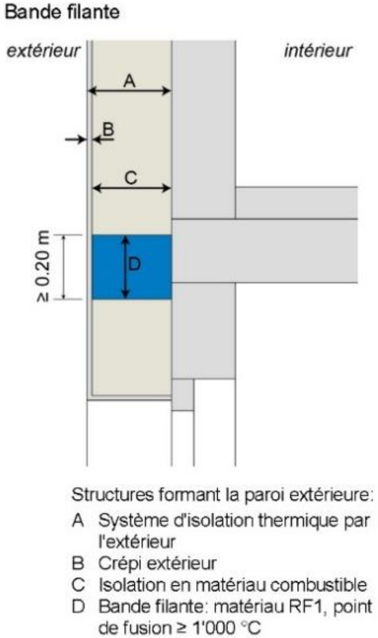
- Exterior wall coverings made of combustible materials are only permitted for medium-rise buildings if access for fire brigade intervention is guaranteed for each façade.

-
- Roofs (the decisive top layer) made of combustible building materials are only permitted for medium-rise buildings if access for the fire brigade is guaranteed for the roof area concerned.

Peripheral isolation

- External thermal insulation (peripheral insulation) of medium-rise buildings, composed of combustible materials, must be carried out with a system recognized by the AEAI or equivalent. Otherwise, there must be continuous strip protection on each floor, running all around the building, made of RF1 materials (melting temperature > 1,000 °C) and with a height of at least 0.2 m.
- This requirement follows the increase in insulation thicknesses.





Fire protection tape CH-PIR UB 3.2

AEAI Product Directory

Fire Safety & Engineering SA

Page d'accueil **Protection incendie** Prévention des dommages éléments naturels Certification de personnes DE **FR** IT

> Page d'accueil > Protection incendie > Répertoire/Recherche de produits et entreprises

- Nouveautés
- Prescriptions 2015 (valable dès le 01.01.2015)
- **Répertoire/Recherche de produits et entreprises**
  - Adresses
  - Formulaires
  - Informations générales
  - Informations sur le répertoire
  - Règlements
  - Liste des prix
- Publications
- Boutique/commandes
- Contact

Groupes principaux: < tous >

Désignation:

Numéro d'attestation AEAI:

Requérant:

Fabricant:

Classification:

recherche

Facades and compartments

The case of Grenfell Tower in London

- On June 24, 2017, at around 1:00 a.m., a fire broke out on the 4th floor in one of the 129 apartments of this 24-storey (67 m) tower.

- Film Grenfell

- If the firefighters arrived on the scene 6 minutes later, easily controlling the apartment fire, at the same time the fire set the entire building ablaze very quickly from the outside. The fire was not brought under control until 24 hours later.
- This fire caused the death of 71 people.

Facades and compartments

The case of Grenfell Tower in London

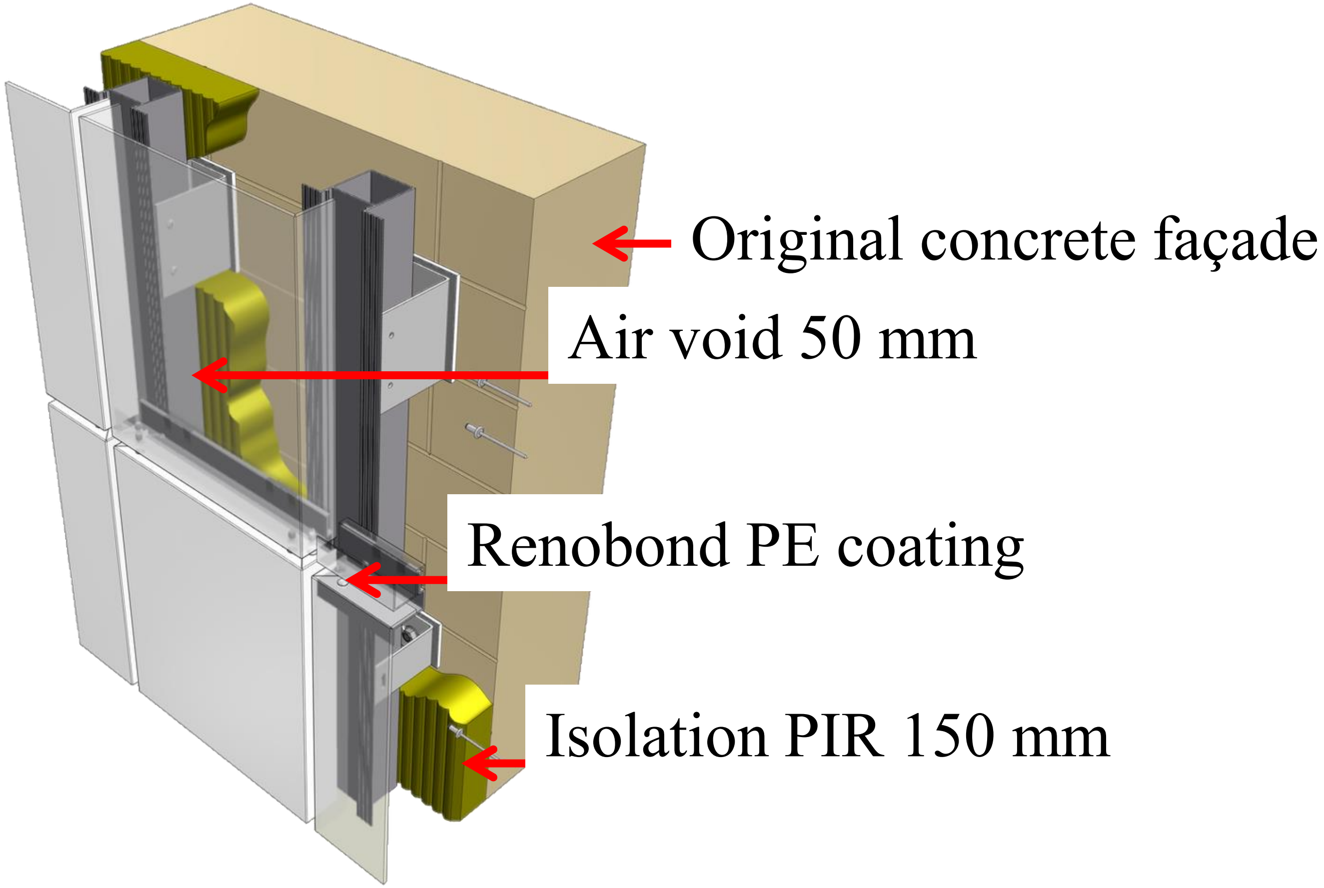
To date and pending the end of the official investigation, here is what we know:

- The façade of the tower was renovated between 2015 and 2016.
- The choice fell on a ventilated façade added to the original concrete façade.
- According to the first investigations, the materials put in place were tested according to the guidelines in force. But the implementation was not done adequately.

Facades and compartments

The case of Grenfell Tower in London

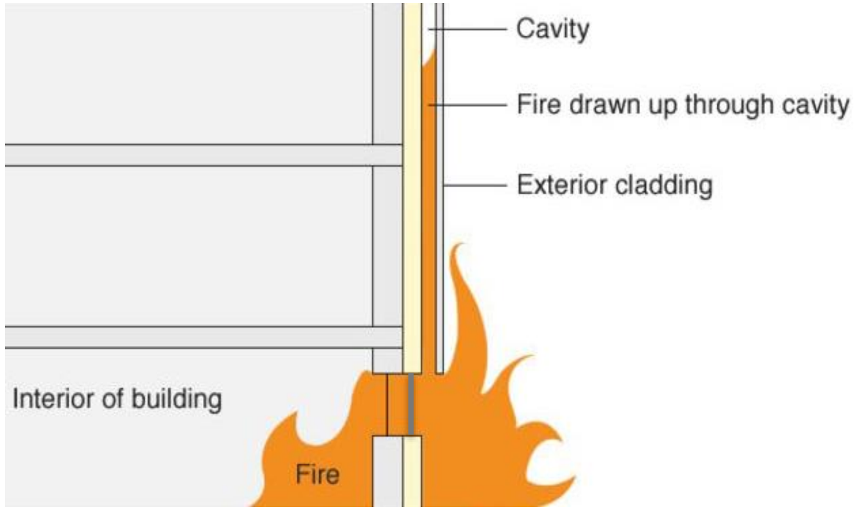
The composition of the façade is as follows:

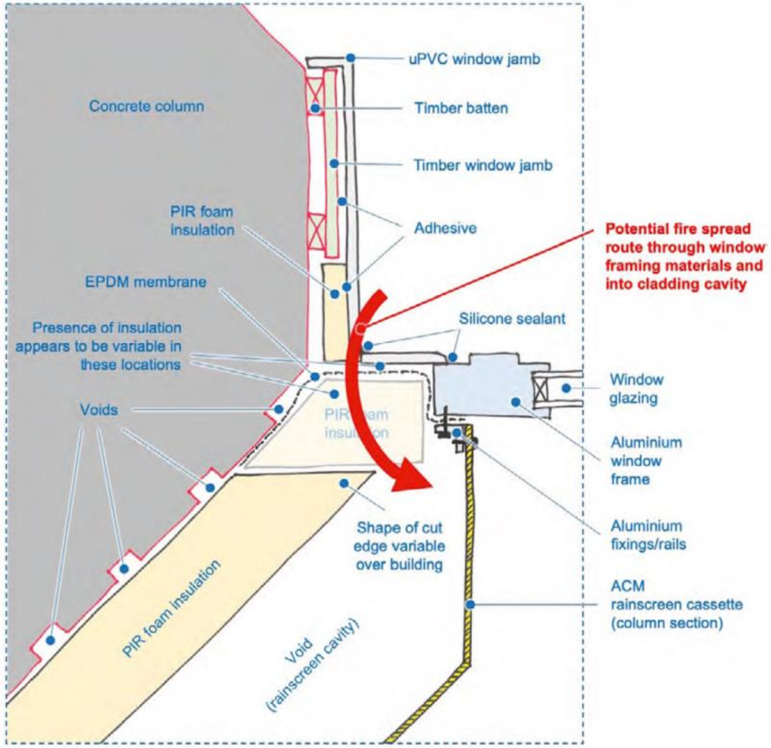


Use of materials

The case of Grenfell Tower in London

The spread of the fire followed this principle:

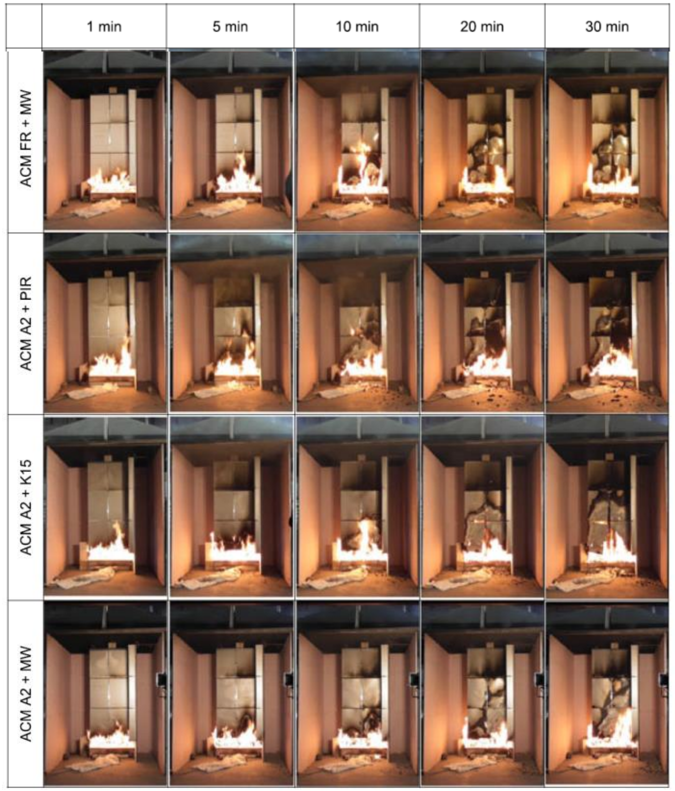


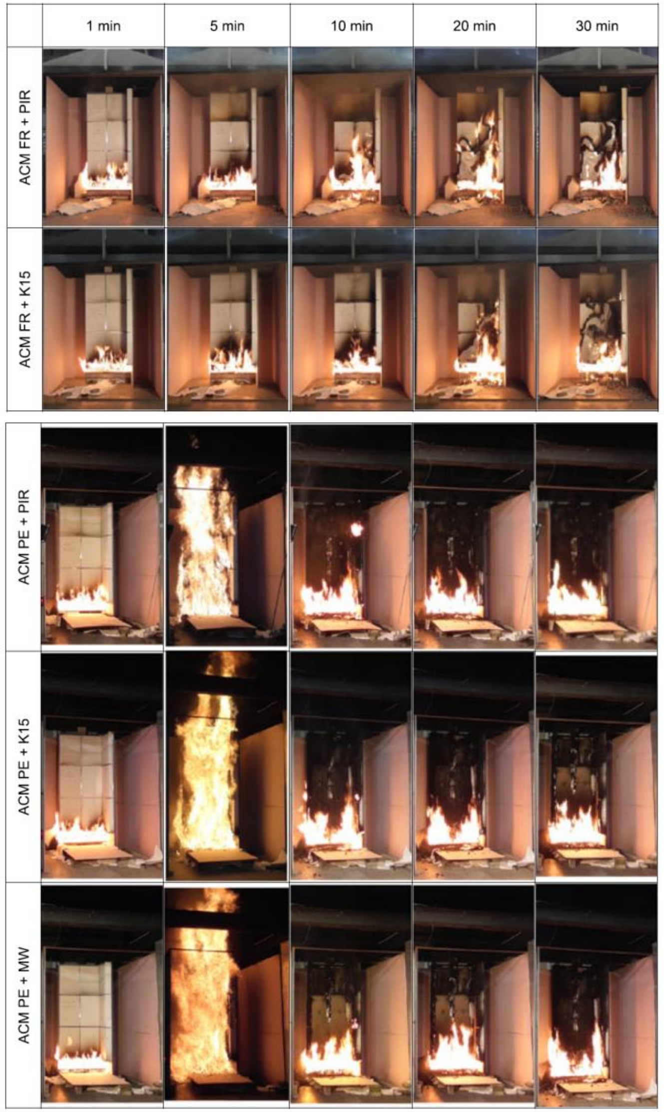


Use of materials

The case of Grenfell Tower in London

Subsequent studies on ACM coatings



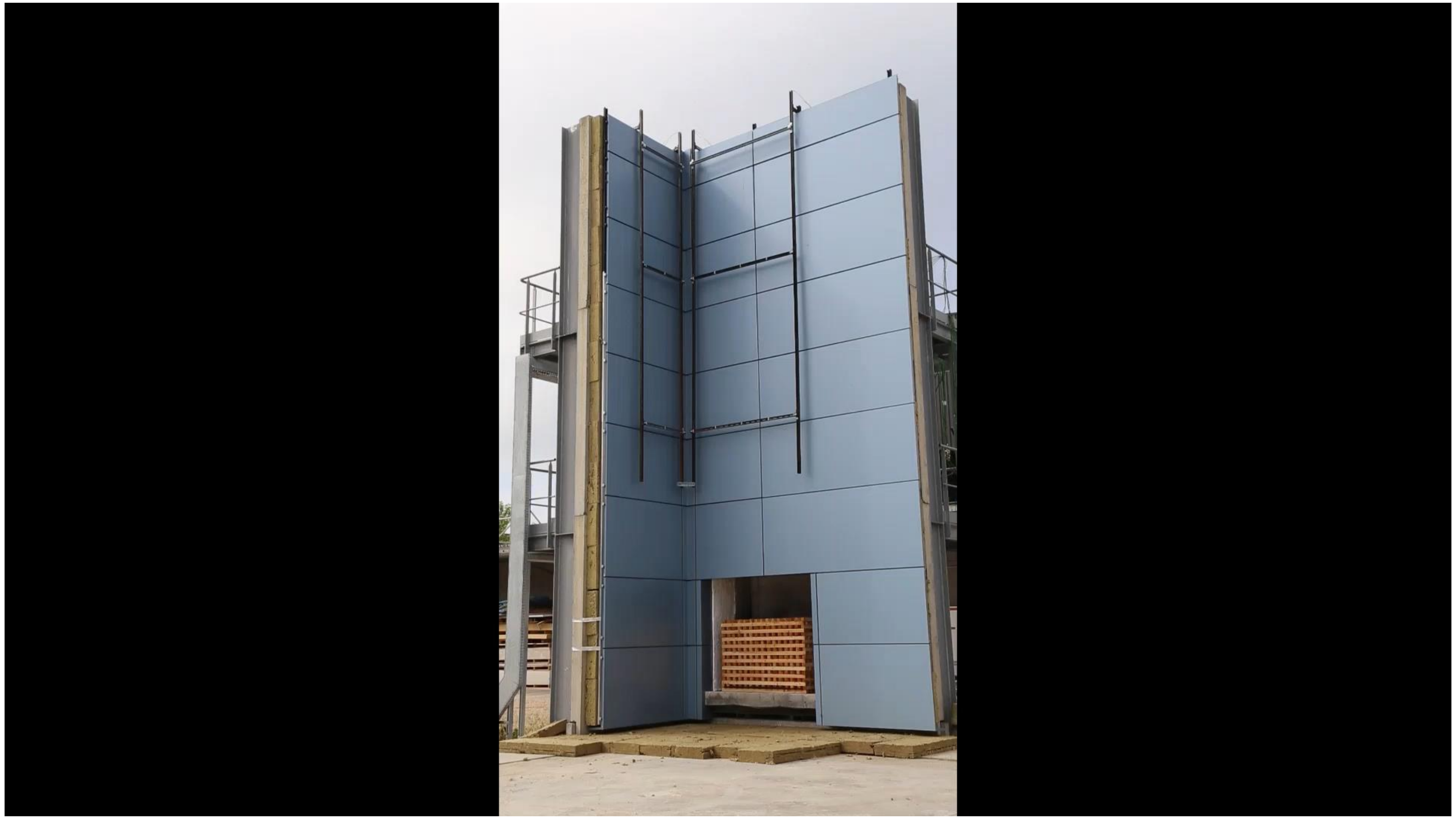


Guillaume E, Fateh T, Schillinger R, Chiva R, Ukleja S. Study of fire behaviour of facade mock-ups equipped with aluminium composite material-based claddings, using intermedate-scale test method. *Fire and Materials*. 2018;1–17.

Use of materials

The case of Grenfell Tower in London

Testing on a façade with ACM-PE coatings



Facades and compartments

Is such a tragedy possible in Switzerland?

- Since 1962, the AEAI standards have specified that the insulation of tall buildings must be non-combustible.
- These standards have only been mandatory throughout Switzerland since 2005!
- There are few tall buildings in Switzerland, but there are a good number of buildings, which are just below the limit of tall buildings with combustible insulation (energy renovation 2008-2015).

- For example, the fire protection measures for plastered thermal insulation have only been valid since 2015.
- To say that such a tragedy is impossible in Switzerland is presumptuous, even if due to the size of our buildings, this type of event should be less dramatic.

Gland, may 2017

DPI 15-15 Fire safety distances, load-bearing systems and fire compartments

Load-bearing system – IATA requirements

Load-bearing systems must be constructed and dimensioned in such a way that:

- They retain their stability sufficiently in the event of a fire.
- Premature ruin of a portion of the structure or the effects of thermal expansion do not result in the destruction of the level or an adjacent level
- The adjoining fire compartments do not suffer disproportionate damage. Attention to the detail of a fire wall (EI 30 or EI 60) hung from a metal roof framework...

Cliché CTICM

Cliché CTICM

Fire doors (e.g. EI)

Example: concrete structure

Fire Safety & Engineering SA

Tableau 4 Éléments de construction en béton

Durée de résistance au feu [minutes]	Dimensions minimales de l'élément de construction [mm]				
	30	60	90	120	180
Enrobage minimal de l'élément de construction [mm]	20	20	30	30	40
Piliers	150	200	240	280	360
Parois	120	140	170	220	300
Panneaux (dalles)	60	80	100	120	150
Dalles champignons	150	150	150	150	200
Dalles plates	150	200	200	200	200
Épaisseur des solives	100	150	200	300	400

Le tableau 4 est applicable pour des qualités de béton normales (résistance normale à la pression) sans prise en compte de son éclatement. Des défaillances comme des éclatements du béton de recouvrement (par ex. pour des éléments de construction en béton hautes résistance), perte de l'adhérence ou inclinaison de l'armature de compression doivent faire l'objet de preuves spécifiques.

Tableau 7 Dalles

Durée de résistance au feu [minutes]	Épaisseurs minimales [mm]				
	30	60	90	120	180
Dalles mixtes : - tôle d'acier profilée / panneaux en béton armé	80	100	120	-	-
Planchers en terre cuite/planchers en poutres de béton armé (planchers hourdis), chape en béton de 4 cm, épaisseur totale	-	160	190	-	-
Panneaux de béton cellulaire armé	-	-	100	125	150

Fire resistance requirements

Extinguishing systems may be taken into account in determining the fire resistance of the load-bearing system and of the walls and floors forming the fire compartment as well as the permissible extent of the fire compartments.

Catégorie de hauteur		Bâtiments de hauteur moyenne (jusqu'à une hauteur totale de 30 m) [7]			
Affectation	Concept	Système porteur [1]	Dalles d'étage formant compartiment coupe-feu	Parois formant compartiment coupe-feu et voies d'évacuation horizontales	Voies d'évacuation verticales
• Bâtiments d'habitation abritant plusieurs logements • Bureaux • Écoles • Locaux de vente (avec surface de compartiment coupe-feu jusqu'à 1'200 m² et recevant jusqu'à 300 personnes) • Parkings [6] • Industrie et artisanat q jusqu'à 1'000 MJ/m² • Agriculture	Construction	R 60	REI 60	EI 30	REI 60
	Installation d'extinction	R 30	REI 30	EI 30	REI 60

- The load-bearing systems of the underground levels must have a fire resistance equivalent to that of the levels above the natural ground, but at least R 60.

No reduction due to the presence of the sprinkler in the basements.

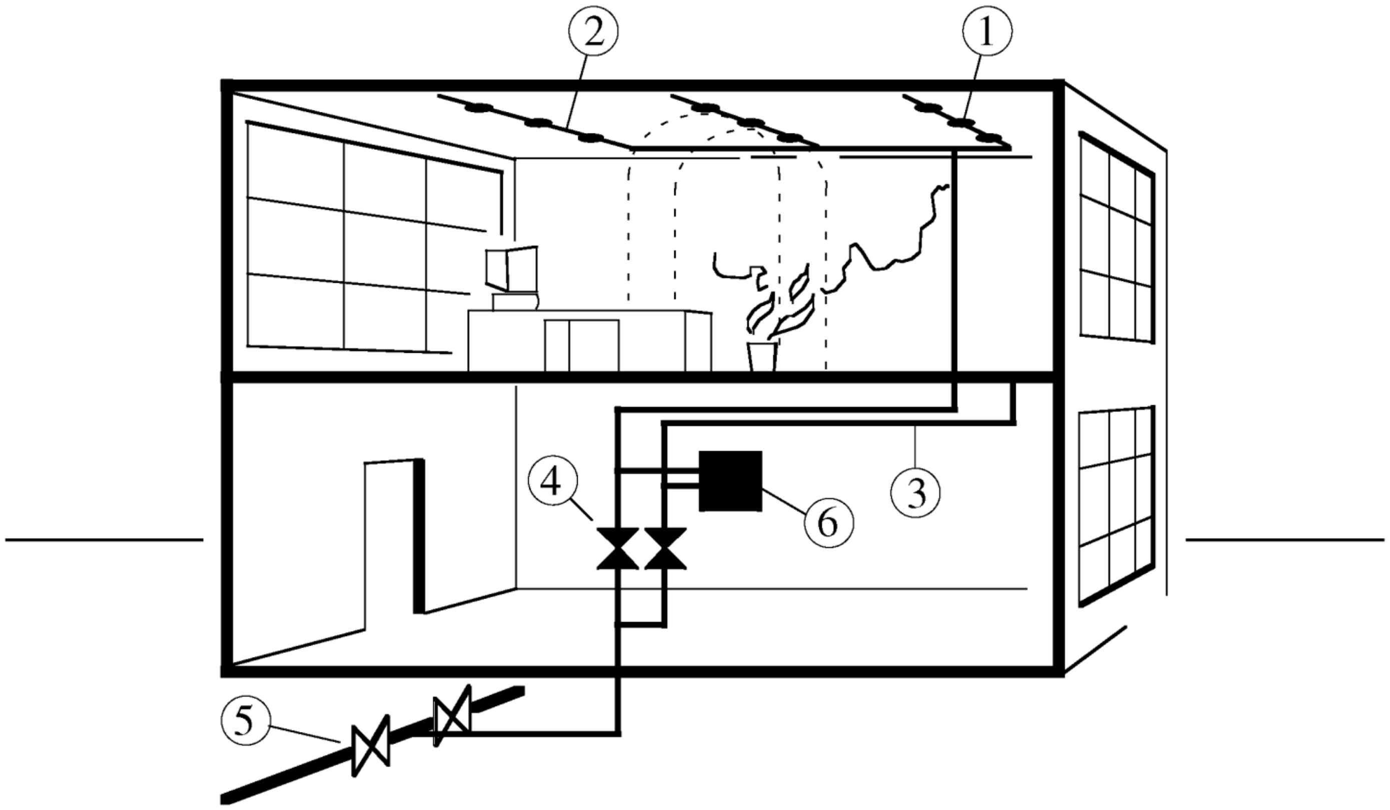
- No strength requirement for top-level structures of multi-storey buildings and no requirement also for single-storey buildings.

DPI 19-15 Sprinklers installation

Sprinklers

Fire Safety & Engineering SA

Working principle



1. Gicleur (*Sprinkler*)
2. Branche
3. Conduite de distribution
4. Centrale
5. Adduction d'eau
6. Centrale de retransmission d'alarme

Sprinklers

Central

Underwater installation (normal)

Underwater installation (risk of freezing)

Sprinklers

Sprinkler heads

orange	57°C
rouge	68°C (standard)
jaune	79°C
verte	93°C
bleu	141°C
mauve	181°C

Sprinklers

Demonstration of effectiveness

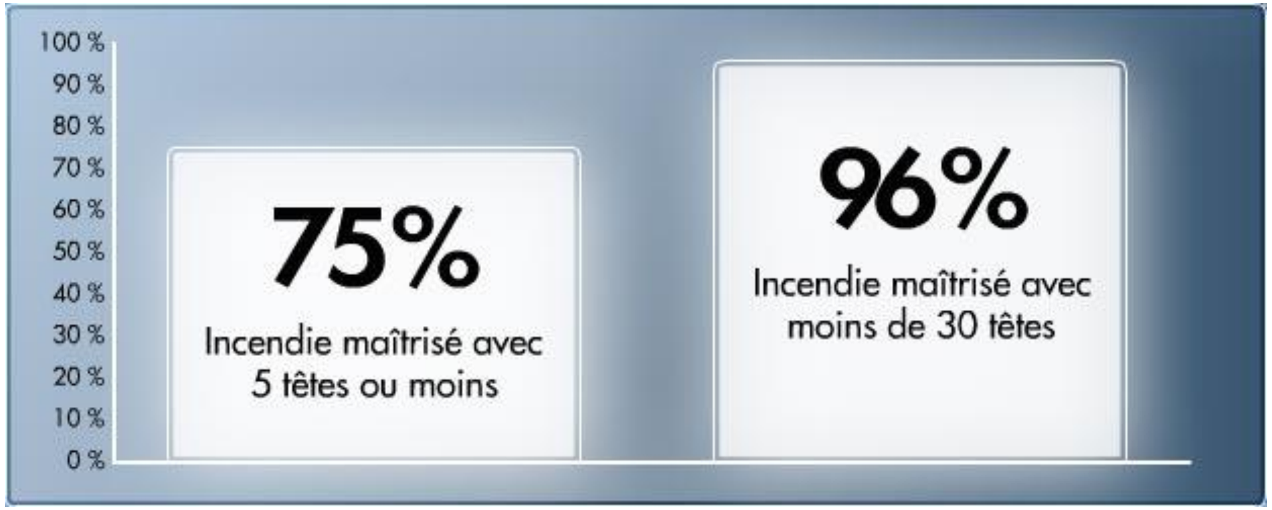
Sprinklers

- The sprinkler heads only go off one by one! The deluges like in the movies are... cinema!

- The sprinkler is triggered at different temperatures (68° for red capsules).
- It can be coupled with early detection (smoke detector, infrared detectors, etc.)
- There are a multitude of systems, but all of them must be approved!

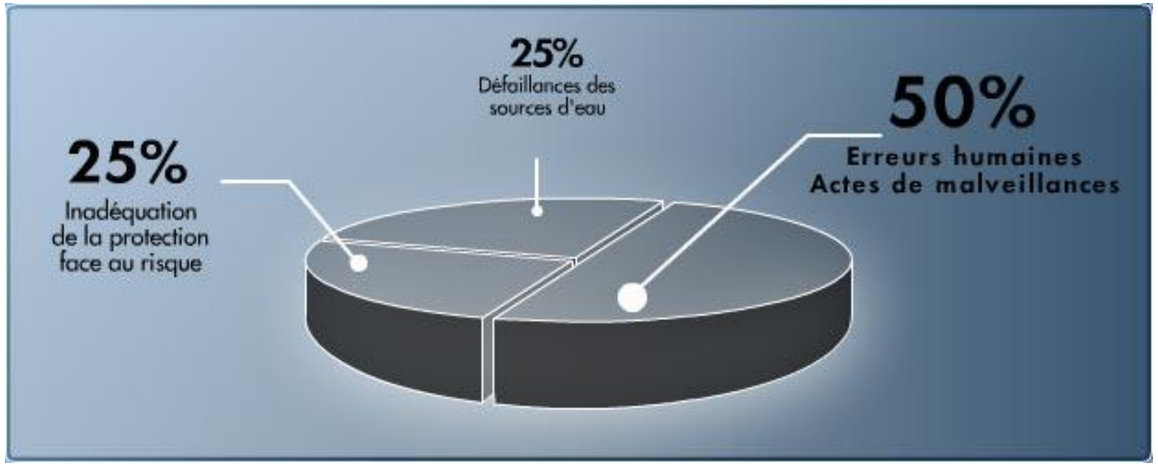
Sprinklers

Sprinkler Efficiency



Reliability : 98% !

The remaining 2%:



DPI 20-15 Fire Detection Installations

Fire detection

Action mode

Purpose of detection:

- Detect and report the start of a fire.
- Alert people in danger.
- Alert the fire brigade.
- Operate fire protection equipment.

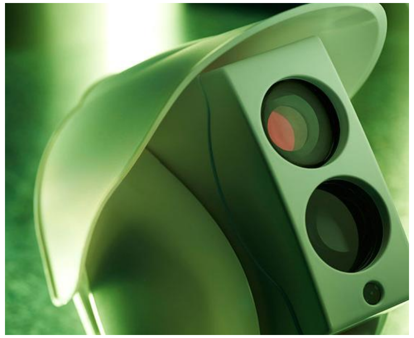
Fire detection

There are several types of detectors:

- Smoke detectors.

- Flame detectors.

- Line detectors.



Fire detection

How a multi-sensor detector works

1. Two IR light sources
2. The rays from the two light sources are scattered by the smoke particles in the measuring chamber where they are picked up by the photoreceptor.
3. Thanks to the two sources, we can capture the light and dark smoke particles.
4. The maze prevents accidental reflections. In addition, it prevents dust from coming into the measuring chamber.
5. The temperature is measured by the redundant sensors.
6. The concentration of CO is measured.

Fire resistance of composite floors

Mixed Flooring

Fire in the Broadgate building in London in 1990

- Office cabinet with 14 floors composed of mixed steel-concrete floor
- Temperatures reached exceed 1000 °C for more than 2 hours
- Significant deformation of the floor (more than 600 mm) but no ruin.
- The total damage is £25 million but the cost to the structure is only £2,500,000.

Mixed Flooring

Post-fire observation of the actual behaviour of composite floors in the 1990s showed that although they had been subjected to extreme temperatures and for periods longer than the ISO 834 fire, they had not suffered any ruin.

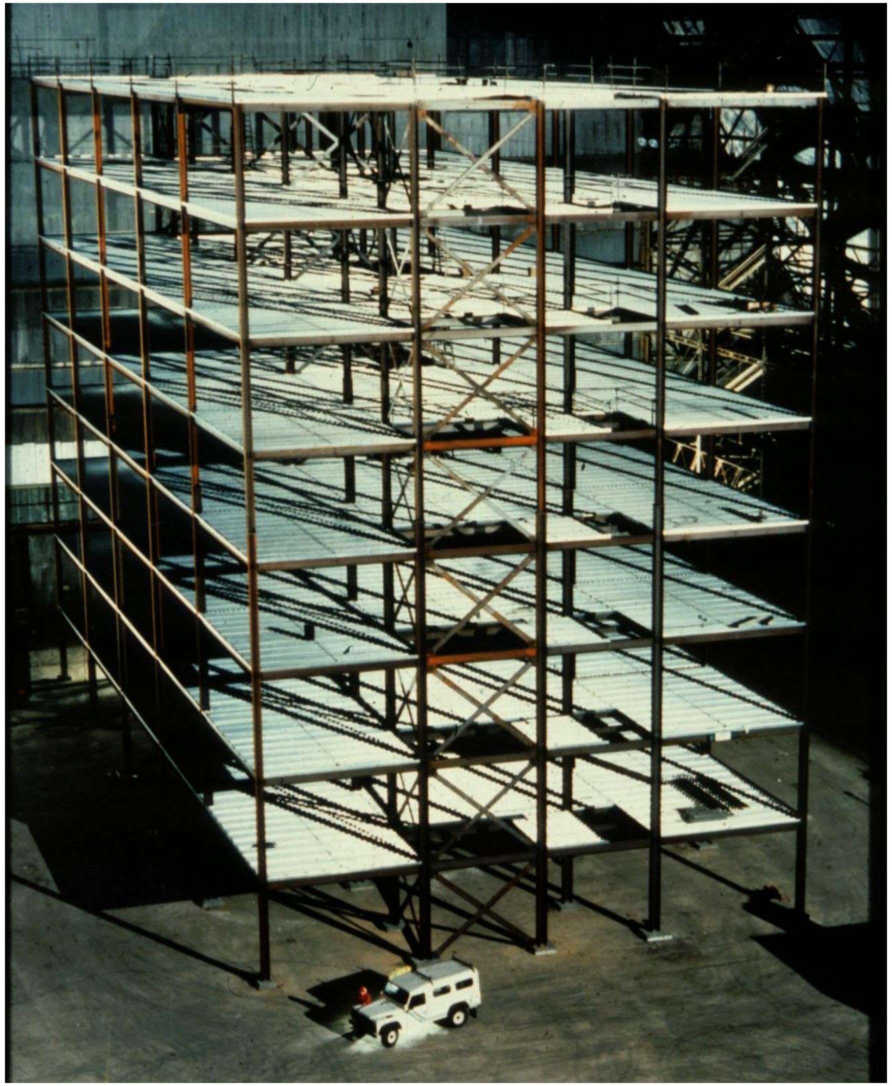
In September 1996, a fire structure research programme was set up at the Building Research Establishment's Cardington Laboratory (UK).

These fire tests carried out on structures composed of composite steel-concrete floors have shown that the overall strength of these elements is greater than that given for isolated elements.

They showed that a membrane effect occurred in the concrete slab on this type of structure.

Mixed Flooring

View of the test building in Cardington (UK)



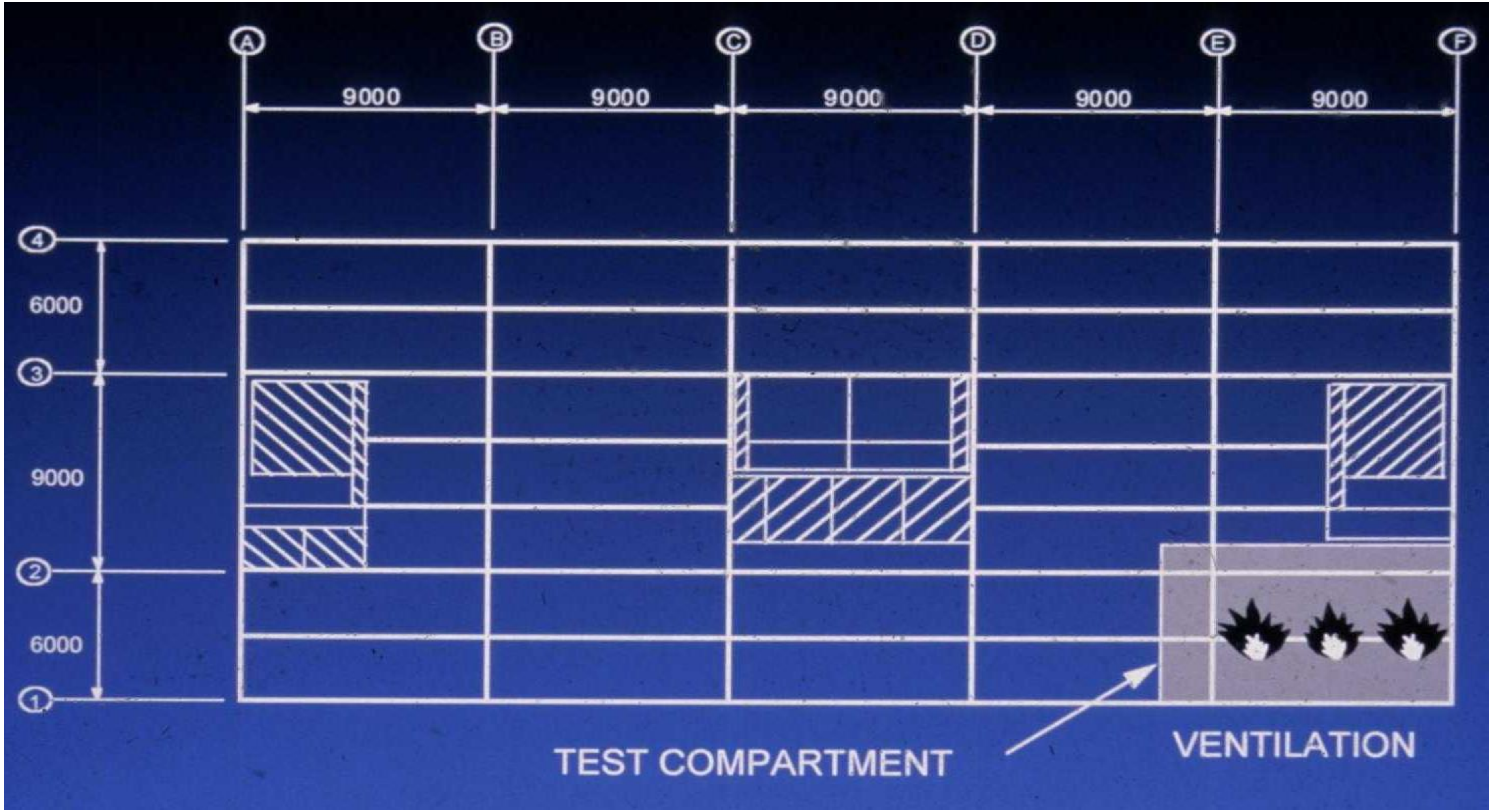
Mixed Flooring

Main Building Specifications

- Length 42 m in 5 spans of 9 m
- Width 21 m in 3 spans of 6 m, 9 m, 6 m
- Floor height: 4.2 m
- Steel structure: UB for beams and UC for columns
- Composite slab: lightweight concrete with a total height of 130 mm in sheet metal
- Reinforcement mesh: 142 mm^2/m'
- Applied Loads: Sandbags (Load depends on the test).

Mixed Flooring

Corner Compartment Testing



Mixed Flooring

Corner compartment test: preparation

Compartment walls made of hollow bricks

Fire load with wooden stick: 45 kg/m^2 (780 MJ/m^2)

Mixed Flooring

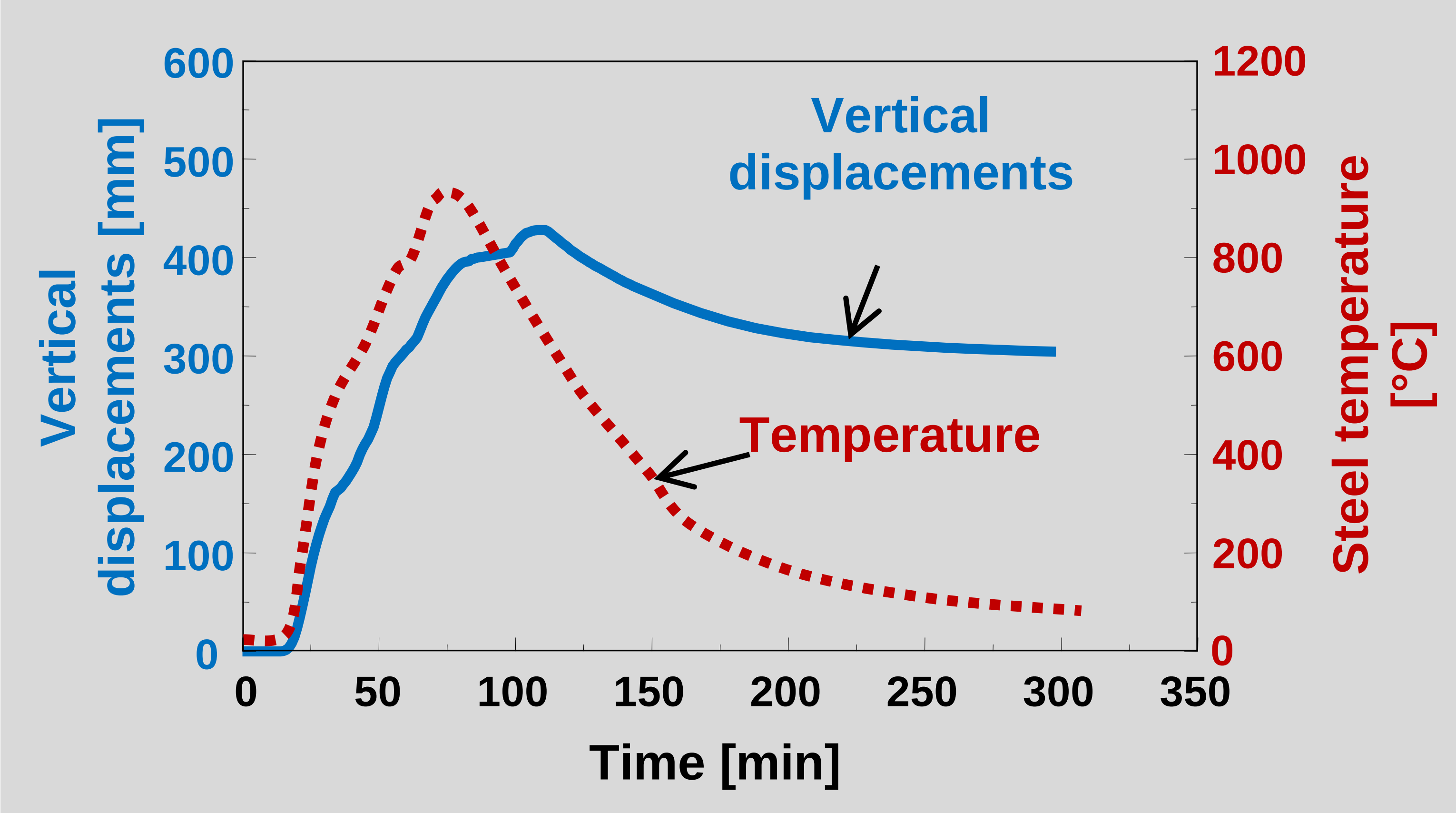
Corner compartment test: experimental results

Fire during the test

Floor deformation after the test

Mixed Flooring

Corner compartment test: experimental results



Observations

- Maximum temperature in steel ≈ 1014 °C
- Maximum floor deformation ≈ 428 mm

Mixed Flooring

Corner compartment test: structure after the test

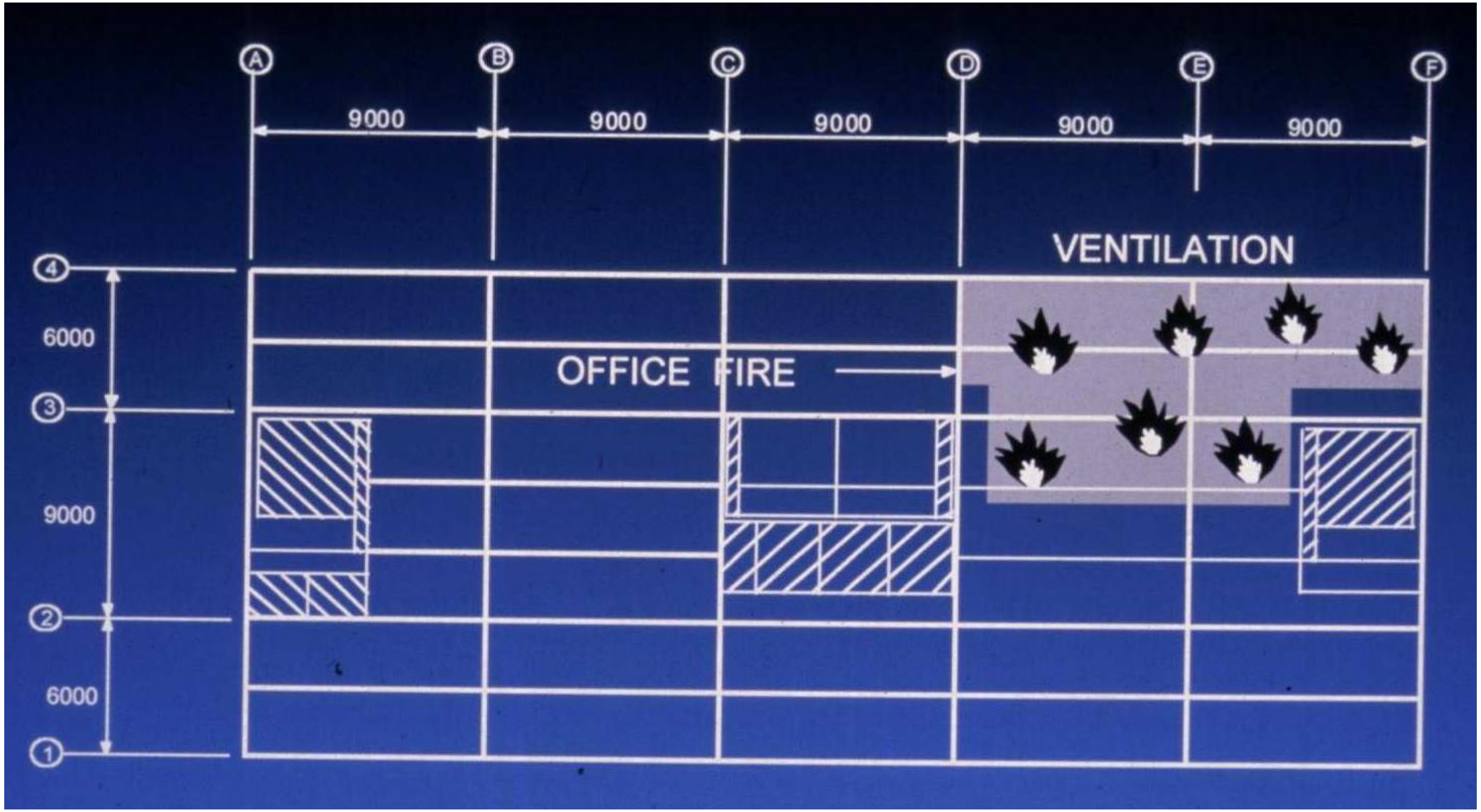
Deformation of the hot part of the floor

Deformation of the metal elements around the protected column

- Conclusion
  - There was no sign of overall floor failure, as well as limited deformation of the floor, despite the high temperatures in the beams.

Mixed Flooring

Demonstration test (an area of more than 130 m²)



Mixed Flooring

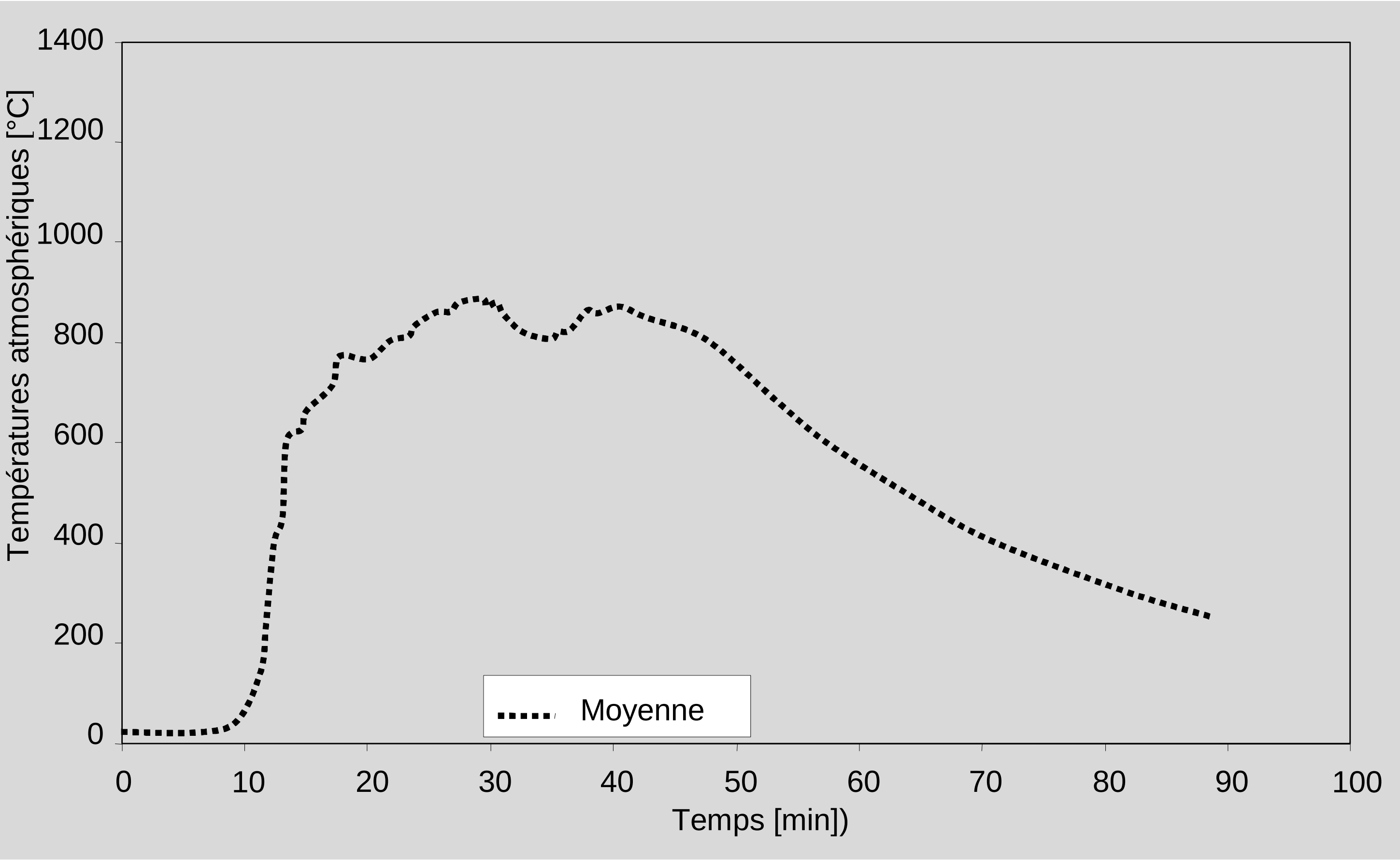
Demonstration test: preparation

Fire Load with Real Office Supplies
(500 MJ/m²)

Openings with normal windows

Mixed Flooring

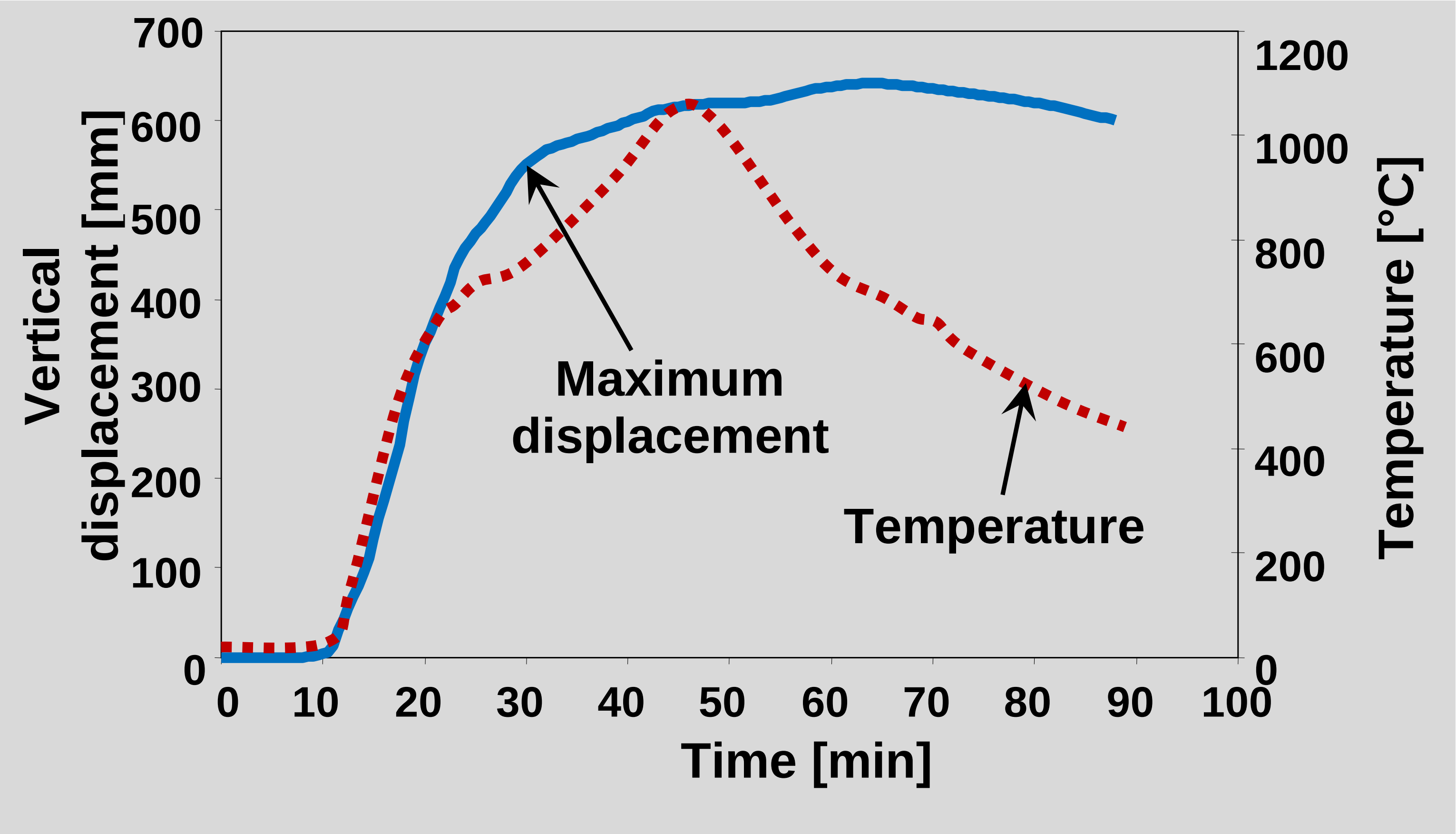
Demonstration test: experimental results



- Observations
  - Maximum gas temperature ≈ 1200 °C
  - Maximum Steel Temperature ≈ 1150 °C

Mixed Flooring

Demonstration test: experimental results



- Observations
  - Significant floor deformation ≈ 640 mm
  - No ruin of the mixed floor

Mixed Flooring

Demo test: structure after the test

Deformation of the hot part of the composite floor

Deformation of metal elements in the right of a protected column

- Conclusion
  - There is no sign of overall ruin of the composite floor, despite temperatures in the steel and significant deformations.

Mixed Flooring

General Notes on Cardington Testing

- Numerous tests with severe fires in this steel building without overall ruin of the structure.
- The results of the fire tests according to the ISO curve gave much better results than the usual tests of isolated elements.
- Excellent overall behavior of the composite floor even if the temperature of the steel beams exceeded 1000 °C.
- Obvious increase in the fire resistance of the composite floor due to the membrane effect induced by large displacements.
- Good structural strength of the composite floor even in the event of a large crack in the concrete.

Membrane action of composite structures in case of Fire (MACS+)

Mixed Flooring (MACS+)

Fire Resistance Assessment of partially protected Composite Floor (FRACOF)

Following these tests, a simple method to calculate this membrane effect was developed by Professor Colin Bailey of the University of Manchester.

It is based on the plastic ruin mechanisms of thin reinforced concrete slabs.

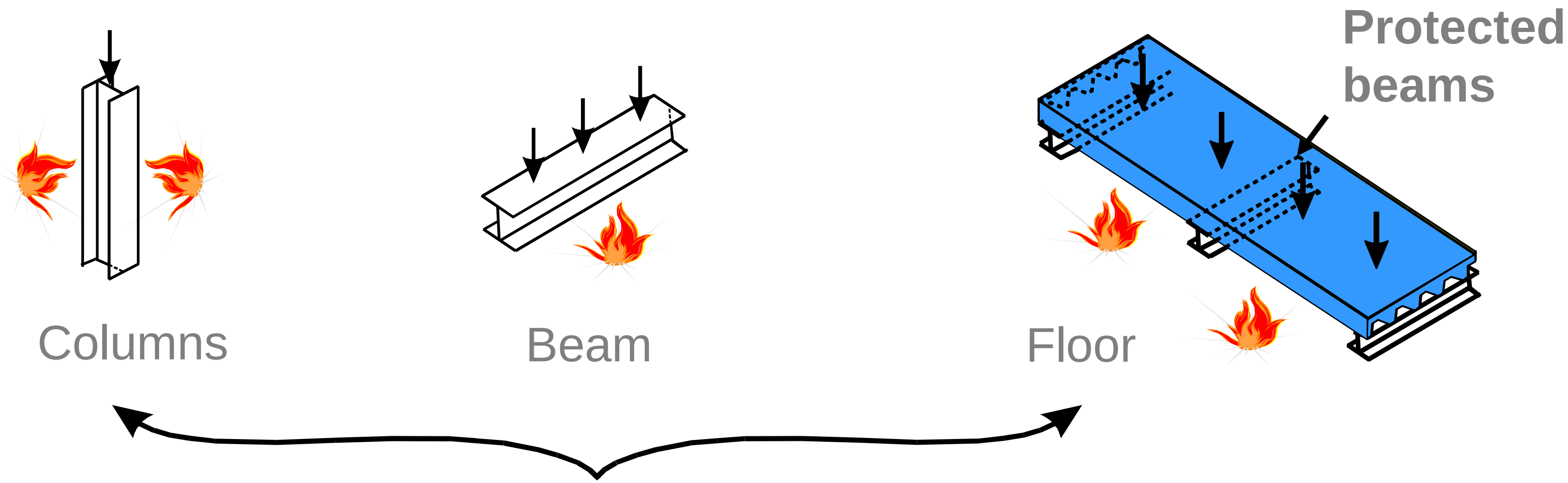
The method has been developed and validated by European research projects and is the subject of a publication under the aegis of the Technical Committee 3 of the Eurocodes:

«Membrane action of composite structures in case of Fire».

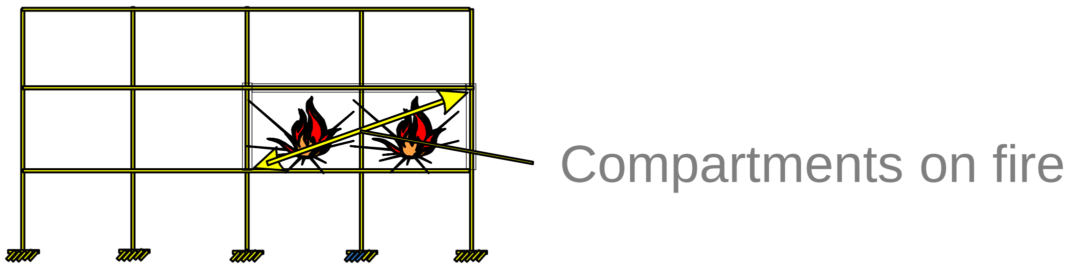
Olivier Vassart – Bin Zhao - 2013

Mixed Flooring (MACS+)

Traditional calculation method



Existing design methods assume that the isolated members will function in a similar way in real constructions

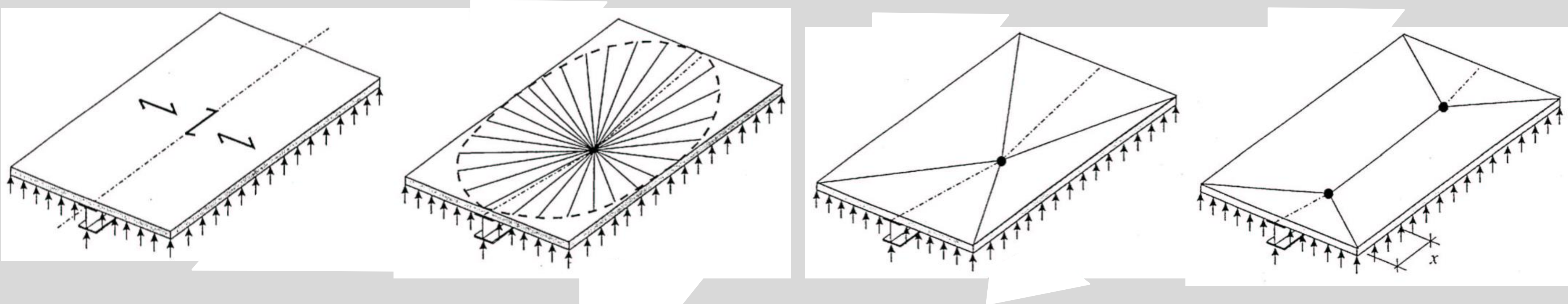


Mixed Flooring (MACS+)

Fire Safety & Engineering SA

Actual Behavior of a Composite Floor with Reinforcing Mesh in the Concrete Slab

Temperature rise during fire

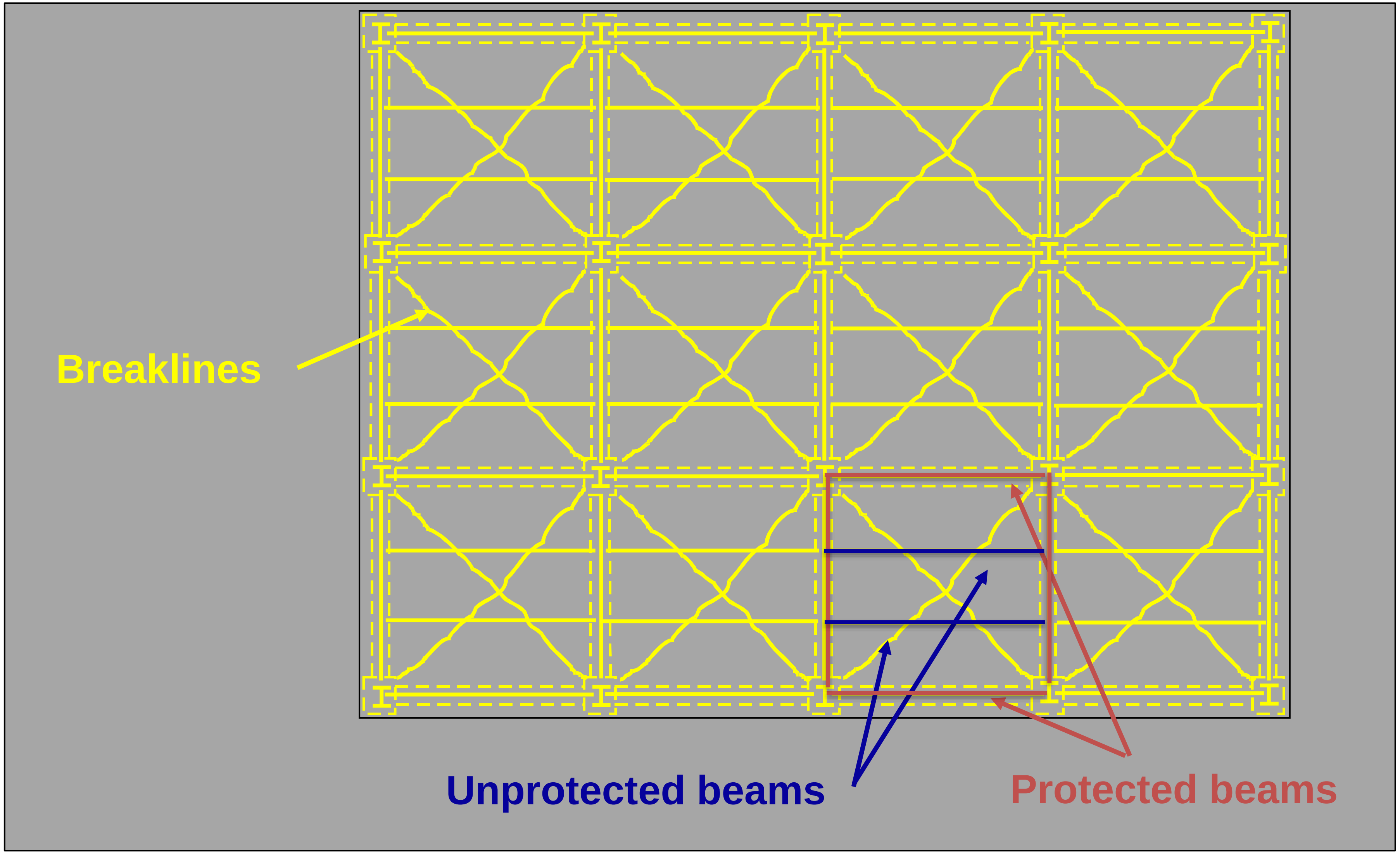


(a) (b) (c) (d)

Bending → **Membrane effect**

Mixed Flooring (MACS+)

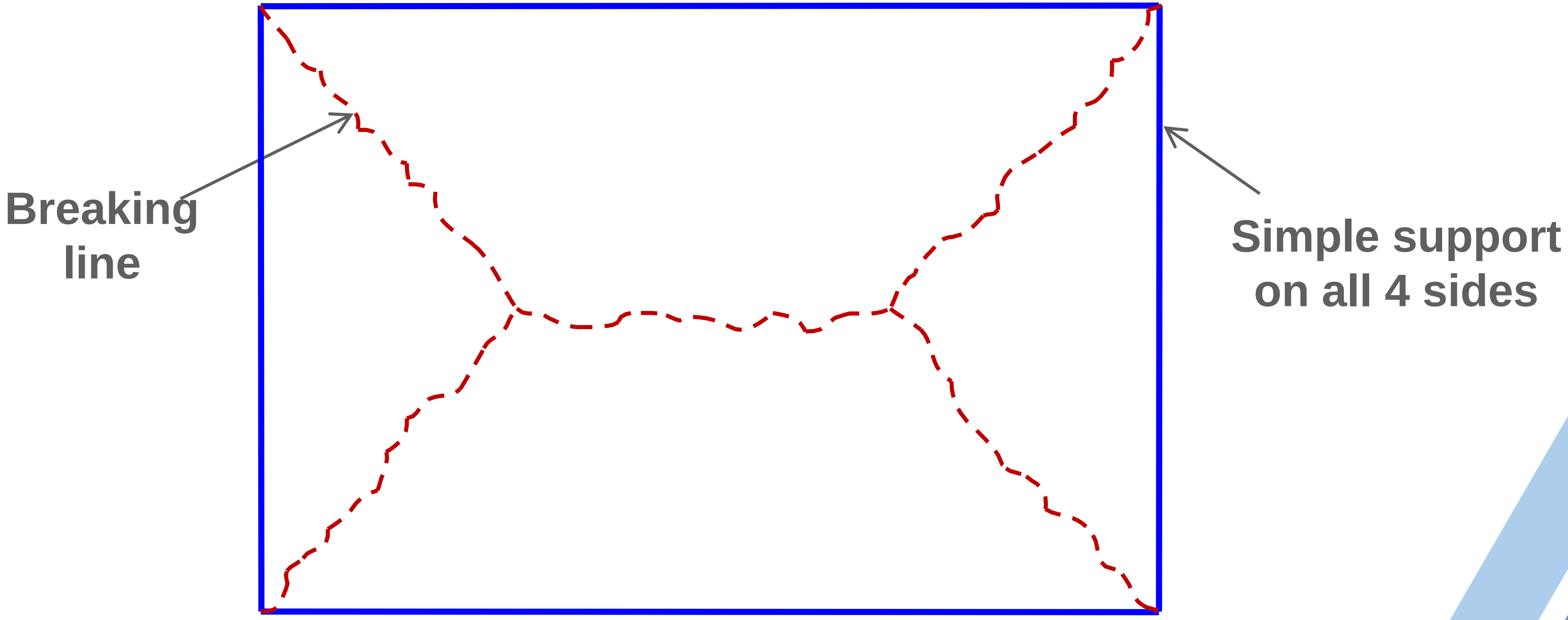
Simple Method for Calculating Slabs at Room Temperature (Bailey)



Composite Flooring (MACS+)

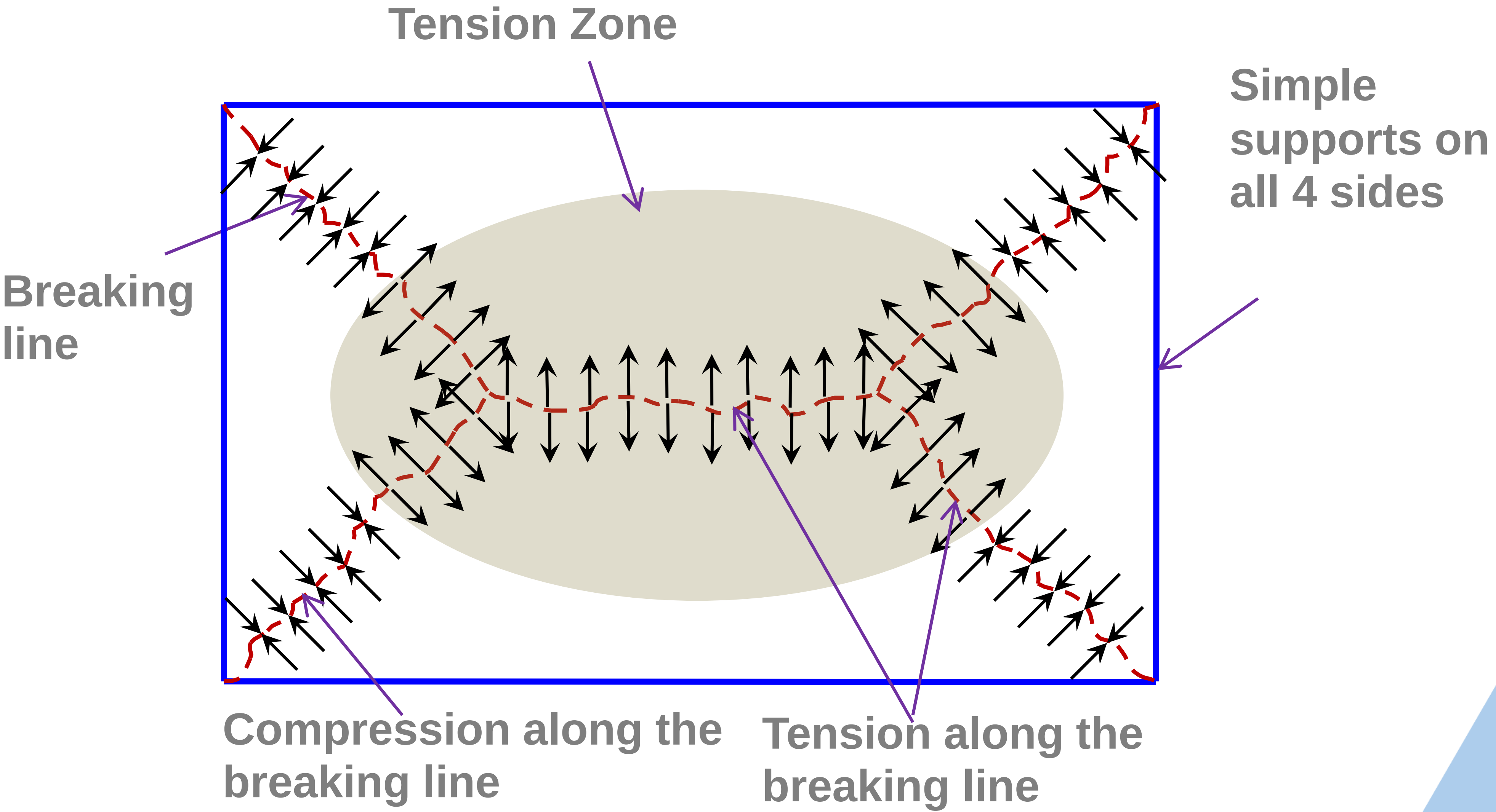
Slab model with 4 vertical supports

- Plastic Break Lines
- No horizontal continuity
- Very conservative approach



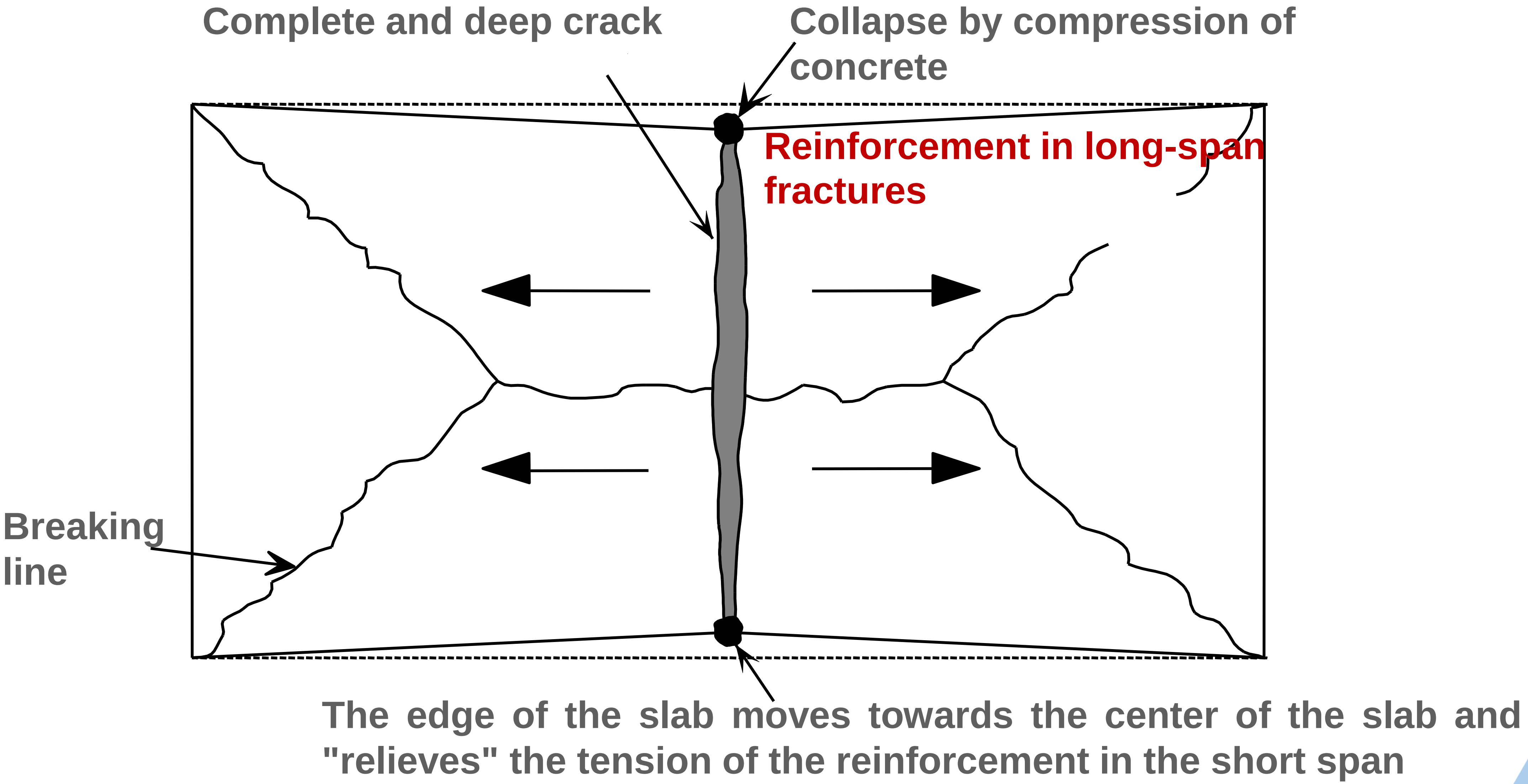
Composite Flooring (MACS+)

Slab model - Membrane effect improving fracture line strength



Composite Flooring (MACS+)

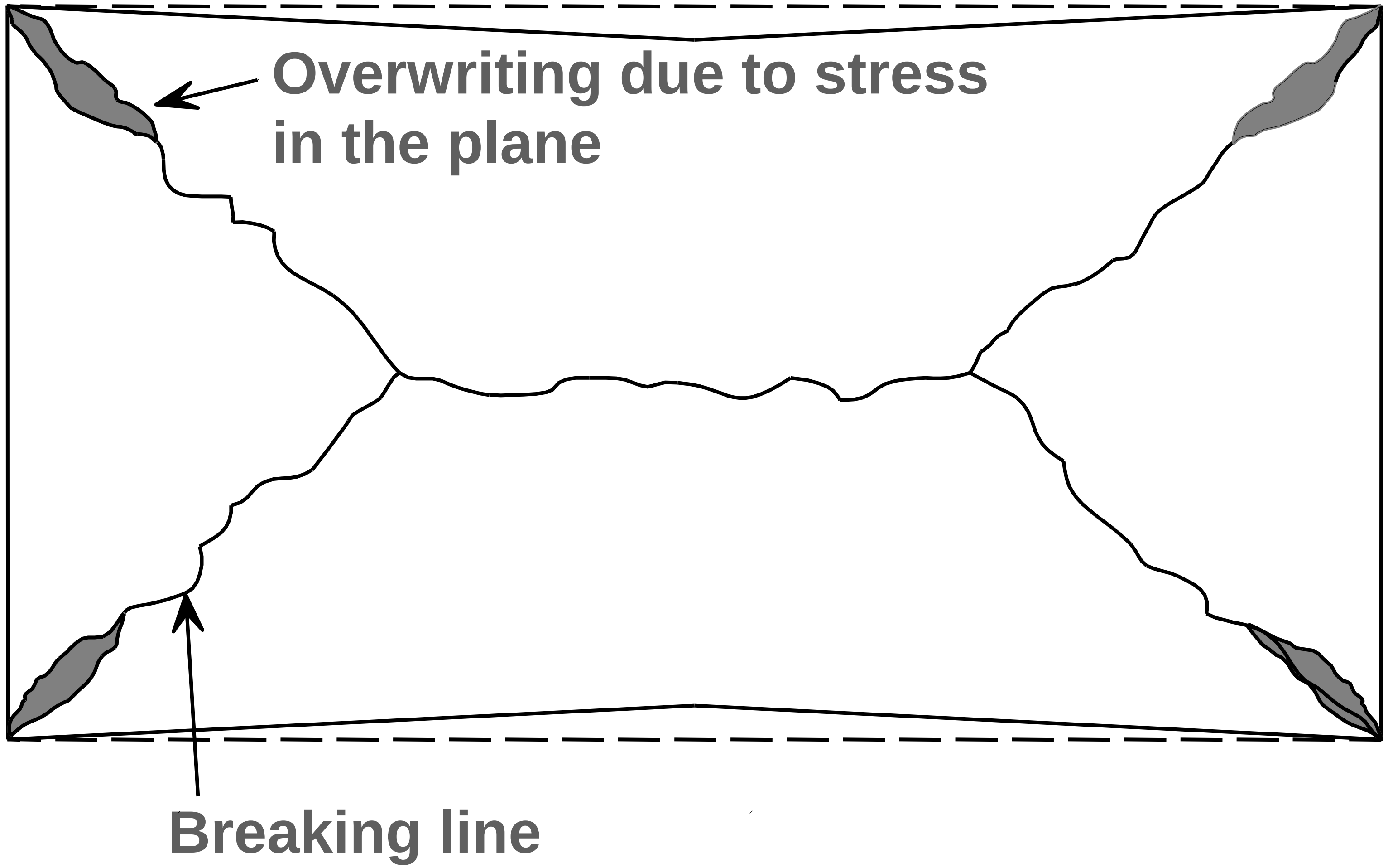
Ruins modes (armature pull ruin)



Composite Flooring (MACS+)

Ruins Modes (Concrete Compression Ruin)

- **Appears more easily in the case of a high rate of reinforcement**



Composite Flooring (MACS+)

Fire Safety & Engineering SA

Ruins Modes (Experimental Evidence)

Failure by tension in the reinforcement

Compression Ruins in Concrete

Composite Flooring (MACS+)

Conservative Assumptions of the Floor Slab Model at Elevated Temperatures

- Reinforcement on supports is considered to be broken.
- The vertical displacements estimated due to thermal curvature are underestimated compared to the experimental values.
- The deformation due to thermal action is calculated based on the shortest span of the slab.
- Additional vertical displacements induced by the thermal expansion prevented when the slab is in a warping state are ignored.
- Any contribution of composite steel sheet is ignored.
- The increase in ductility of the reinforcing mesh with the increase in temperature is ignored.

Composite Flooring (MACS+)

Fire Safety & Engineering SA

- 7 Full-scale tests in Cardington
- 1 Full-scale test by the BRE (cold but simulated with fire)
- 10 Cold tests carried out in the 1960s and 1970s
- 15 Small-scale tests conducted by the University of Sheffield in 2004
- 44 Small-scale cold and fire tests conducted by the University of Manchester
- FRACOF and COSSFIRE tests with fire according to ISO 834 between 2008 and 2009
- Full-scale test carried out by the University of Ulster in 2010

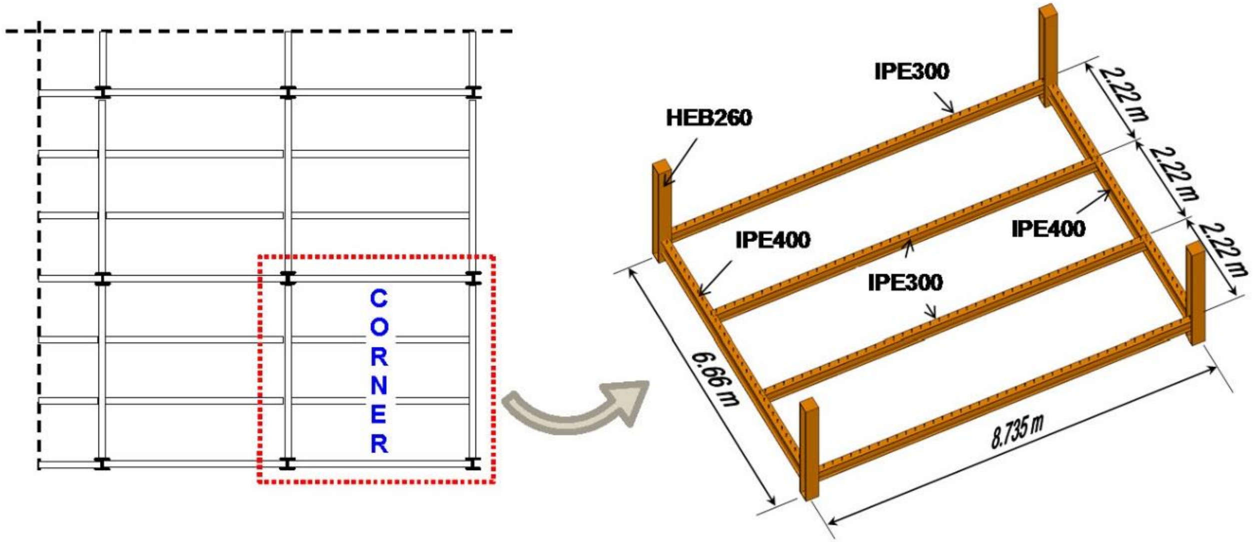
Composite Flooring (MACS+)

22 cold tests and 22 identical hot tests
(both with steel and stainless steel frames)

Method validation testing

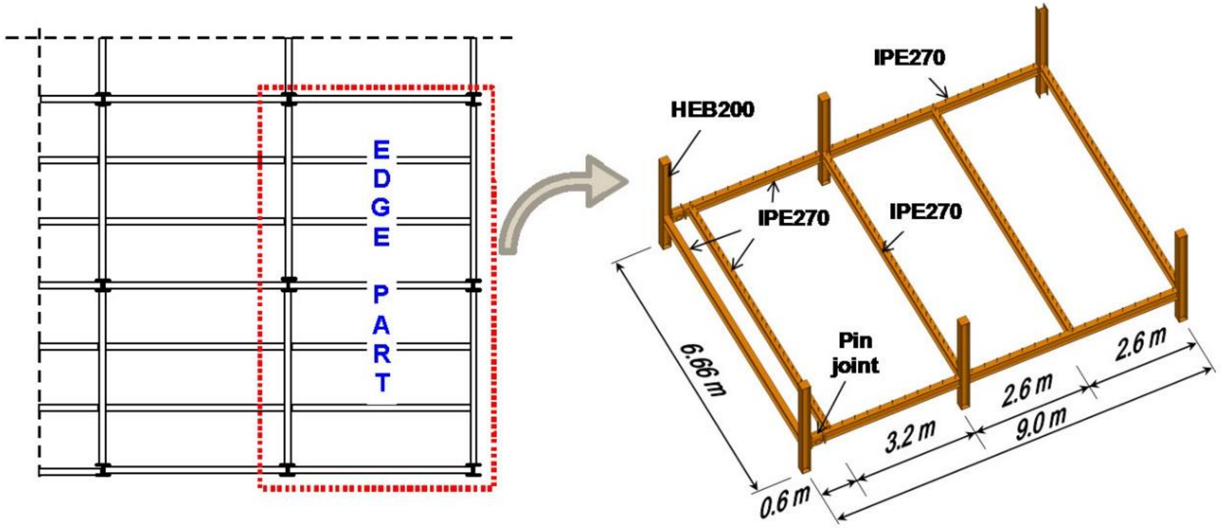
Fracof test

(16 / 01 / 2008)

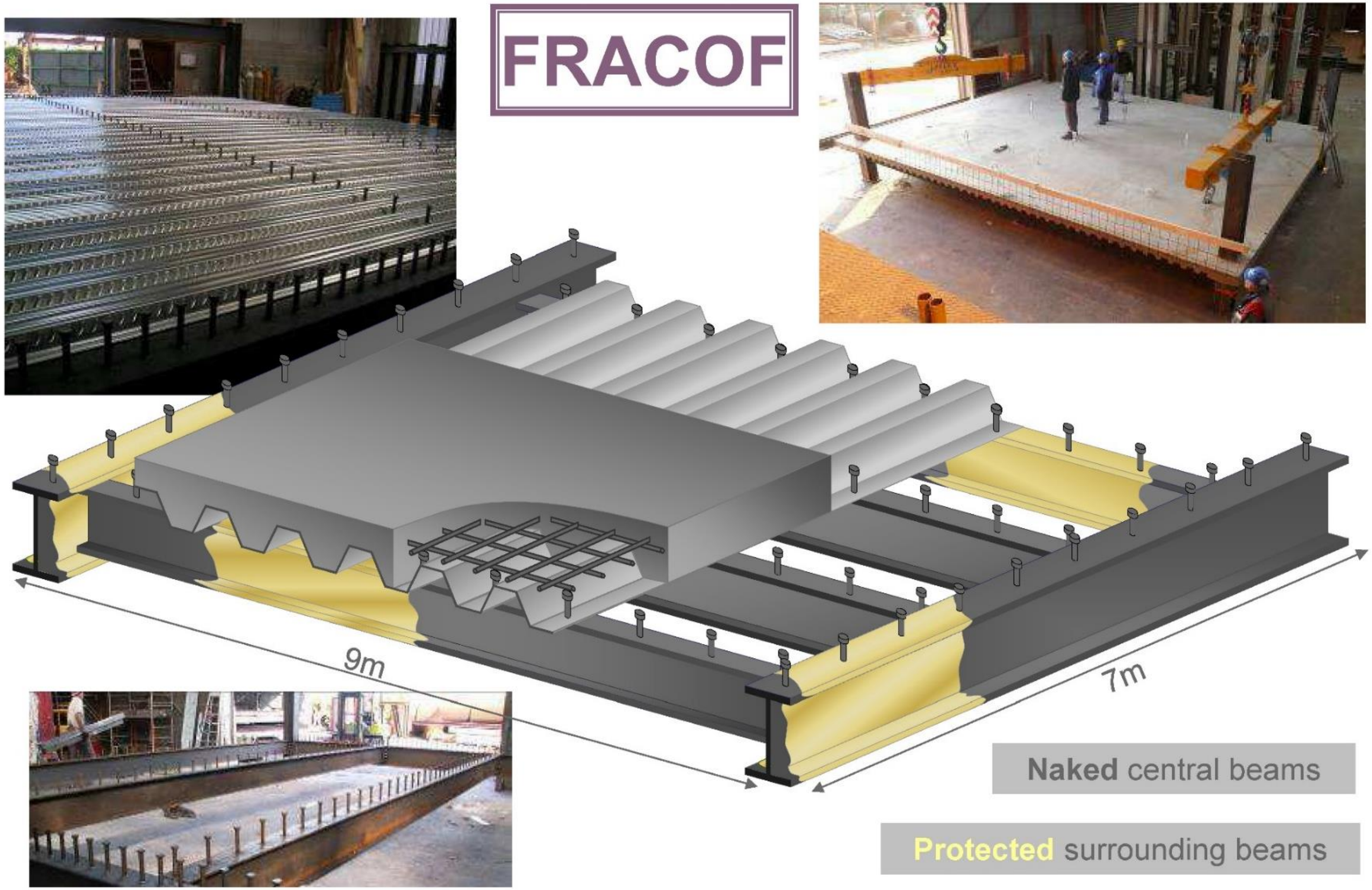


Cossfire test

(16 / 01 / 2009)

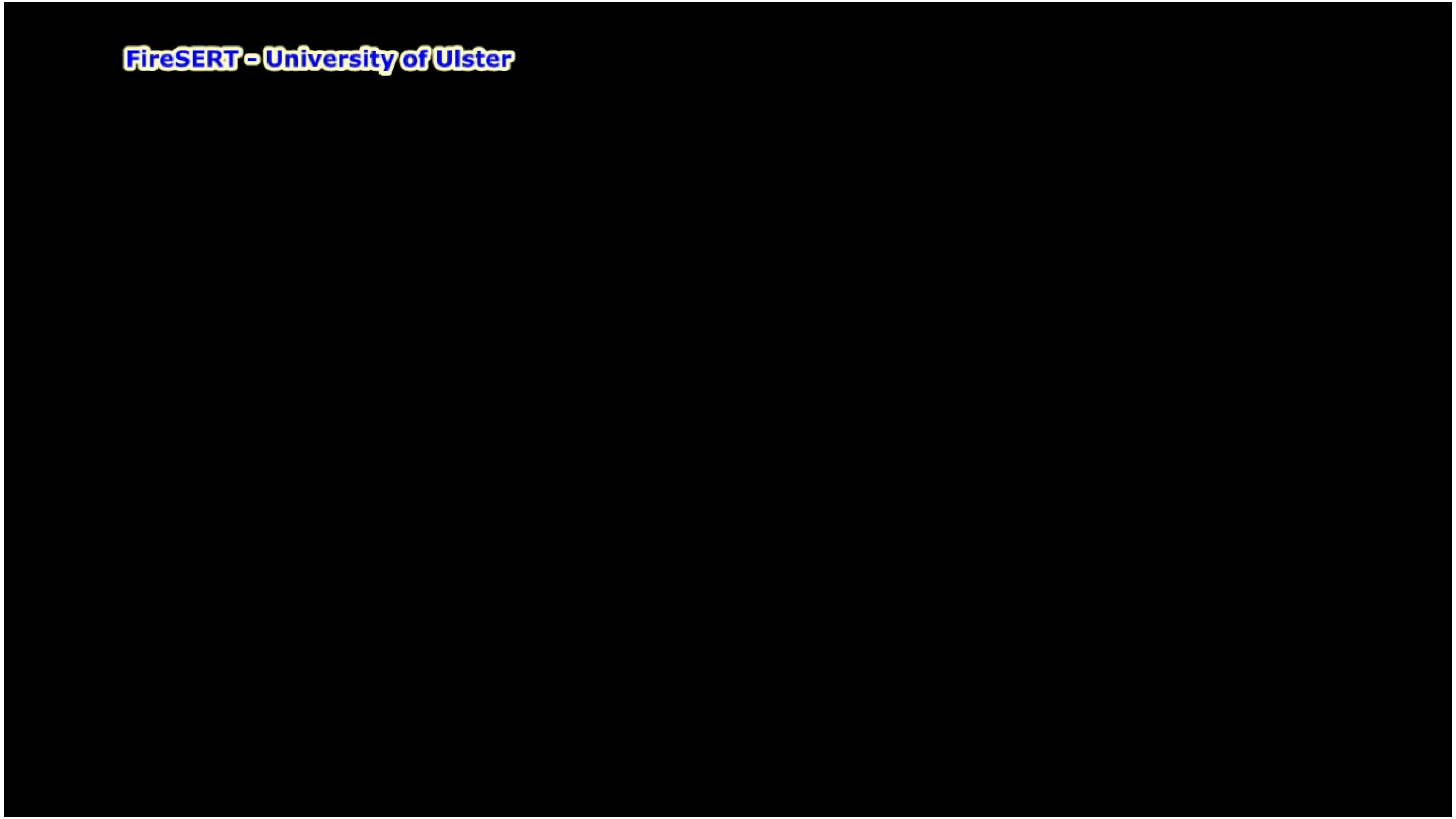


FRACOF test

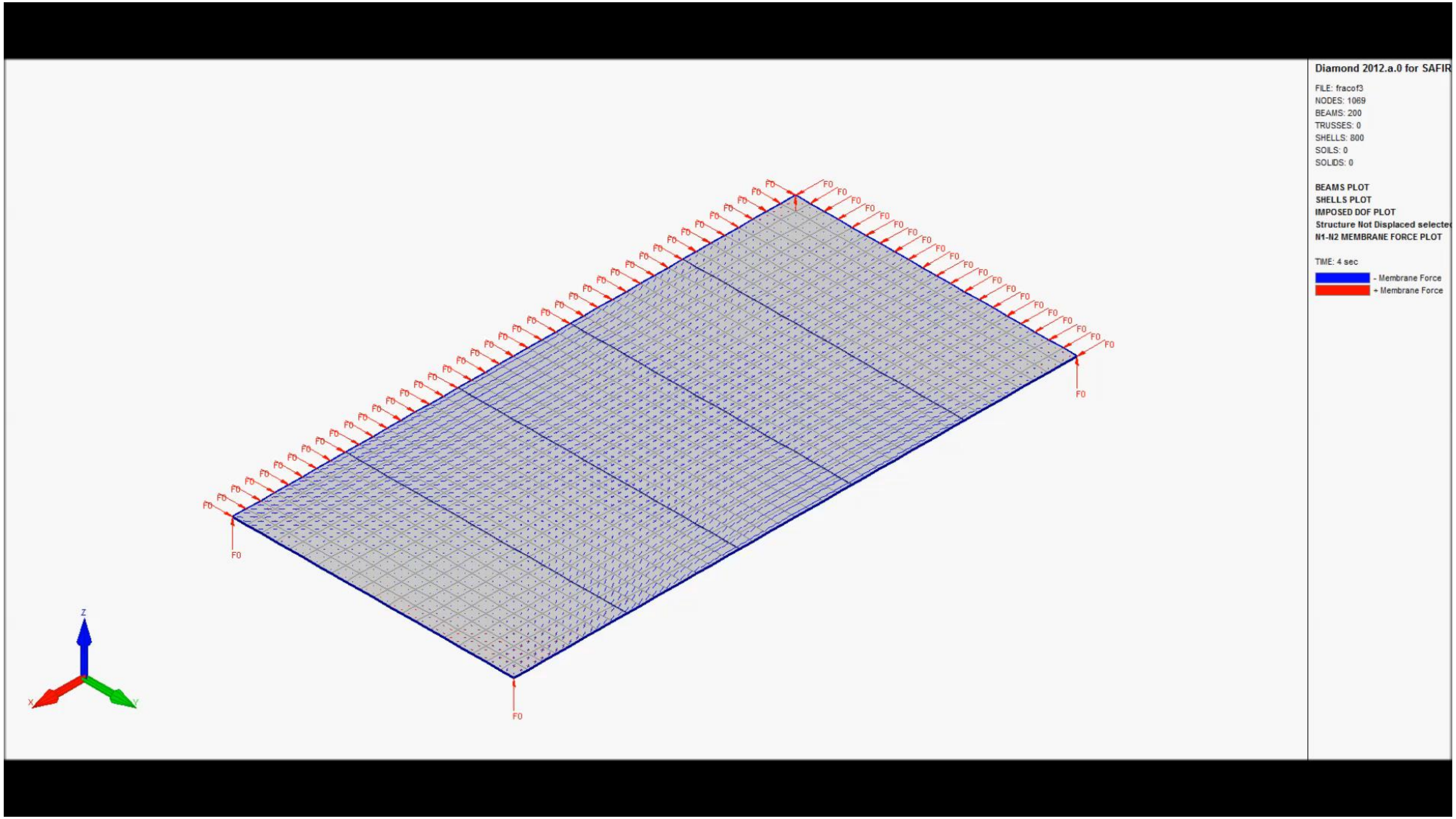


FRACOF
9m
7m
Naked central beams
Protected surrounding beams

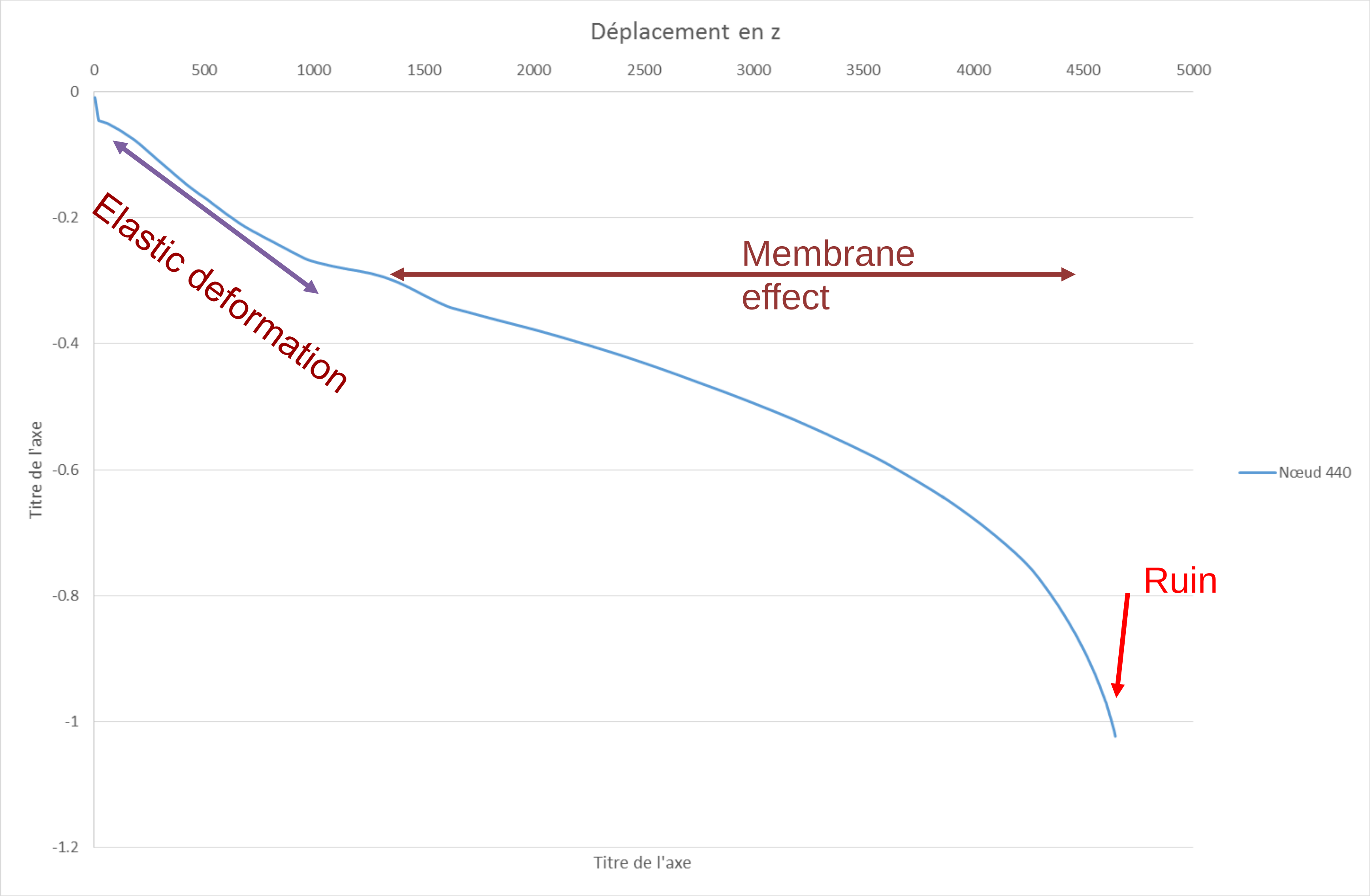
Testing in large compartments



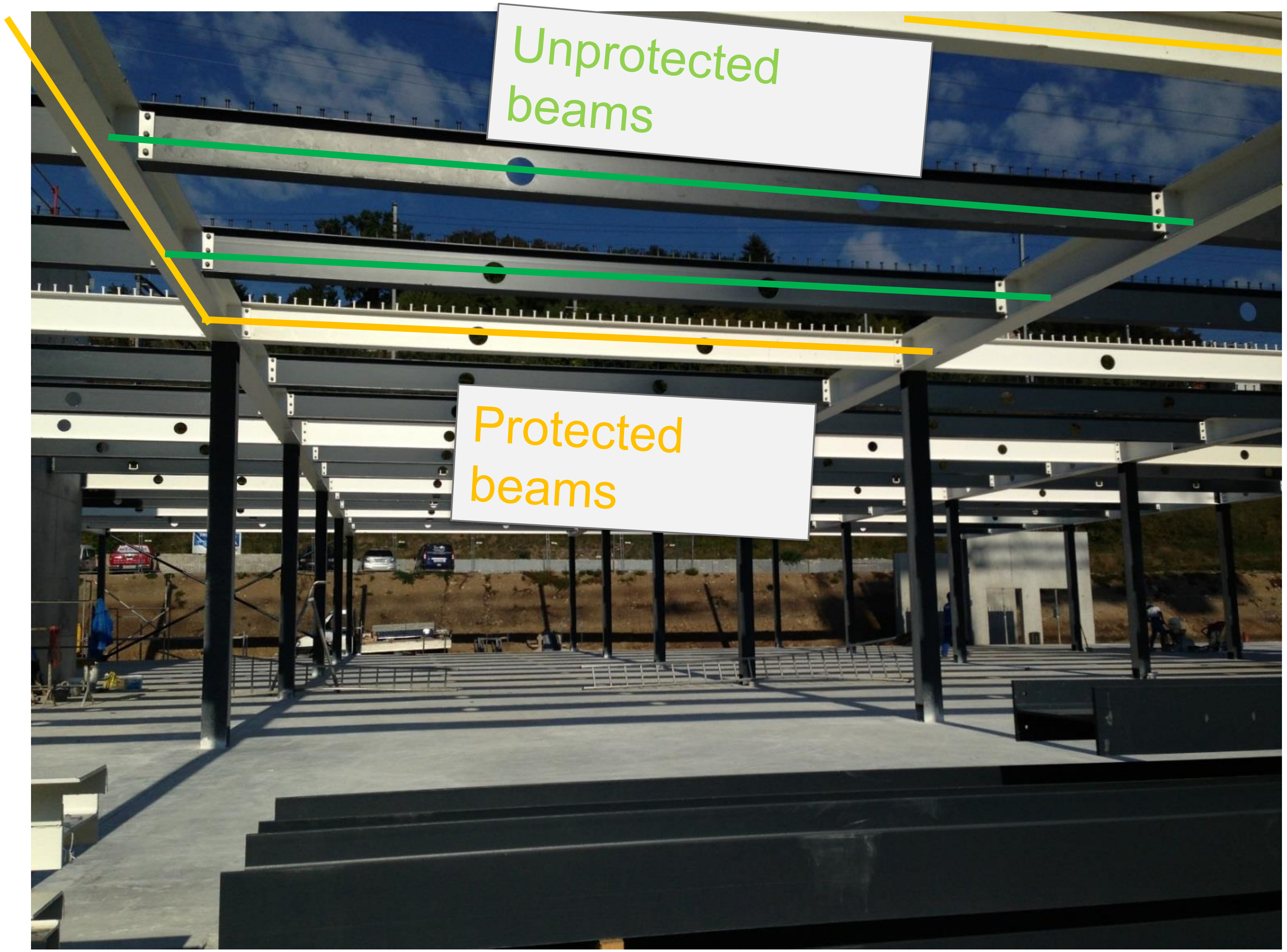
Composite Flooring (MACS+)



Composite Flooring (MACS+)



Application example



Procimmo SA construction site in Puidoux

Temperature assessment of a vertical steel member subjected to LOCAlized FIre «LOCAFI»

LOCAFI Method

General

- In the normative approach, the strength of the structure is verified for a given period of time under the action of the standard fire curve (ISO 834). This usually determines the required thickness of fire protection to meet this requirement.
- The design of steel structures according to this approach usually leads to uneconomic designs, as the influence of many parameters is not taken into account: occupancy, compartment geometry, presence of active measurements and hyperstaticity of the structure.
- In performance-based approaches, advanced methods are used to more accurately assess the fire load, the temperature evolution in the compartment and the overall behavior of this structure under the combination of thermal and mechanical loads.
- The actual behaviour of fire has been the subject of research carried out for more than twenty years throughout Europe by universities and research centres focused on fire engineering

LOCAFI Method

General

- This research led to the development of the Natural Fire Safety Concept (NFSC).
- This concept takes into account the actual fire data that has an influence on the fire behaviour (fire load, fire surface, heat release rate, compartment geometry, wall properties, ventilation conditions,...) in order to enable a more accurate design of the structures vis-à-vis the fire
- More competitive structures are designed with less or sometimes no fire protection, meeting the requirements of local building fire protection regulations.
- By extension, the application of these methods allows for a more efficient use of materials and leads to more sustainable constructions.

LOCAFI Method

General

- For construction typologies where a generalized fire cannot develop (e.g. outdoor structures, open parking lots, atriums, large industrial or transport rooms, etc.), localized fires are an important issue.
- Zone models (one or two zones) are not intended to incorporate the effects of localized fires on structures. The main challenge for this is the calculation of the thermal profiles in the structural elements as a function of the location of the fire and the evolution of this fire over time (diameter, fire load density, RHR, etc.).
- Various recent research projects have developed analytical design methods and demonstrated their validity with experimental evidence.
- The aim of this research was to determine a simple method that could be used by engineers without resorting to complex and computationally intensive (CFD) models.

LOCAFI Method

General

- The current version of EN 1991-1-2 includes an annex dedicated to localized fires where two calculation methods are described (see Appendix A). By applying the Heskestad method, it is possible to evaluate the temperature of the gas (and by extension the temperature of the steel) along the vertical axis of the center of the fire. This method can only be used when the flame does not impact the ceiling and assumes that the flame emissivity is equal to 1.0, which is a conservative assumption.
- In the event that the flame touches the ceiling, the Hasemi method makes it possible to evaluate the heat flows (and by extension the temperature of the steel) received by the elements located at ceiling level.

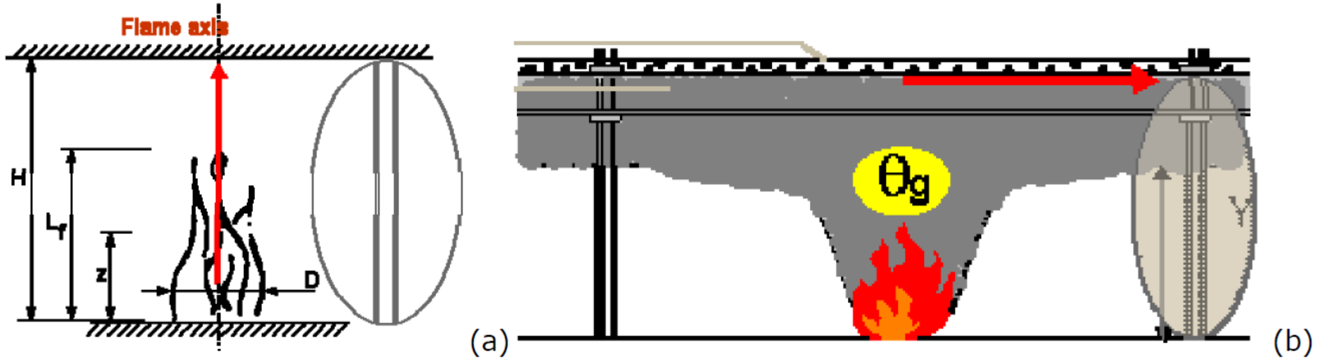
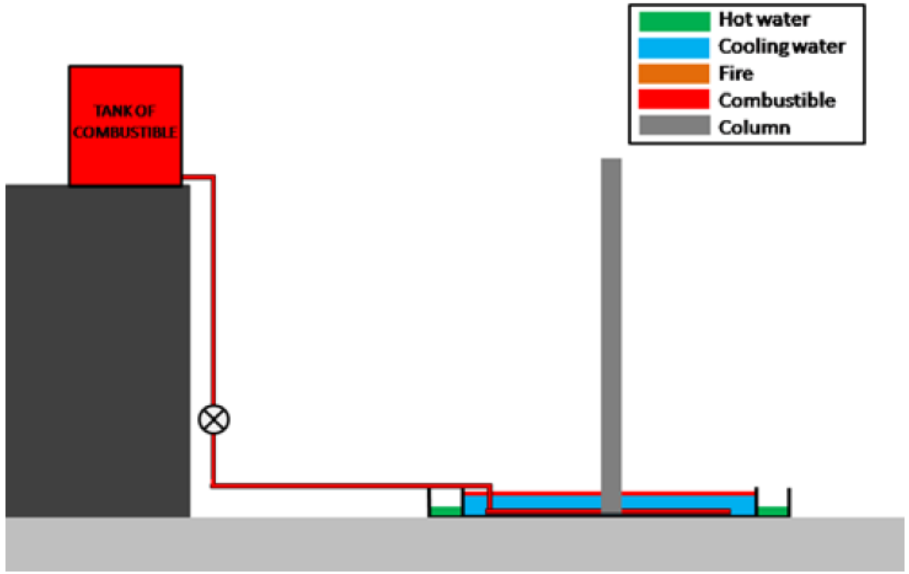


Figure 0-1 : Field of application of Heskestad method (a) and Hasemi method (b)

LOCAFI Method

Experimental tests

A first series of 24 tests was carried out at the University of Liège and made it possible to determine the temperatures of the columns in the middle of the flames.



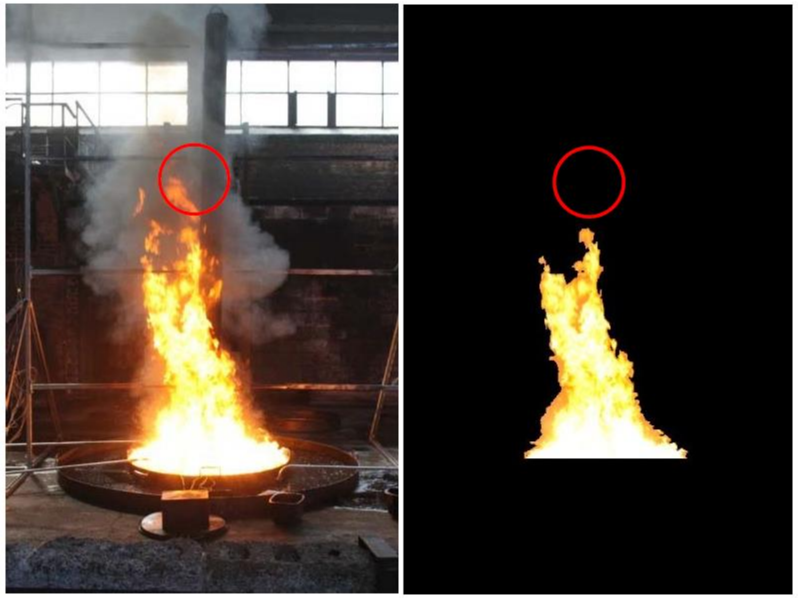
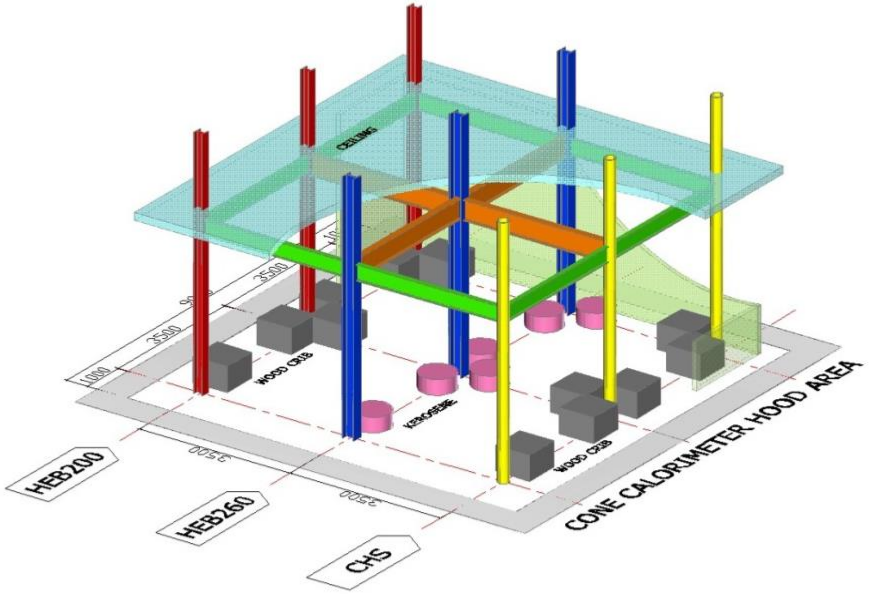


Figure 2-11 : Flame length measurement – Matlab

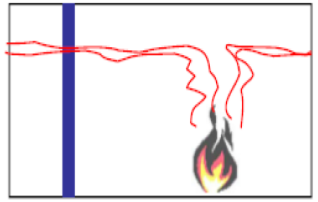
LOCAFI Method

Experimental tests

A second series of tests was carried out at the FireSERT laboratory under a 20 kW range hood. The purpose of this second series of tests is to identify the temperatures along the columns on fires located at a distance from the columns and to see the influence of a slab located above.



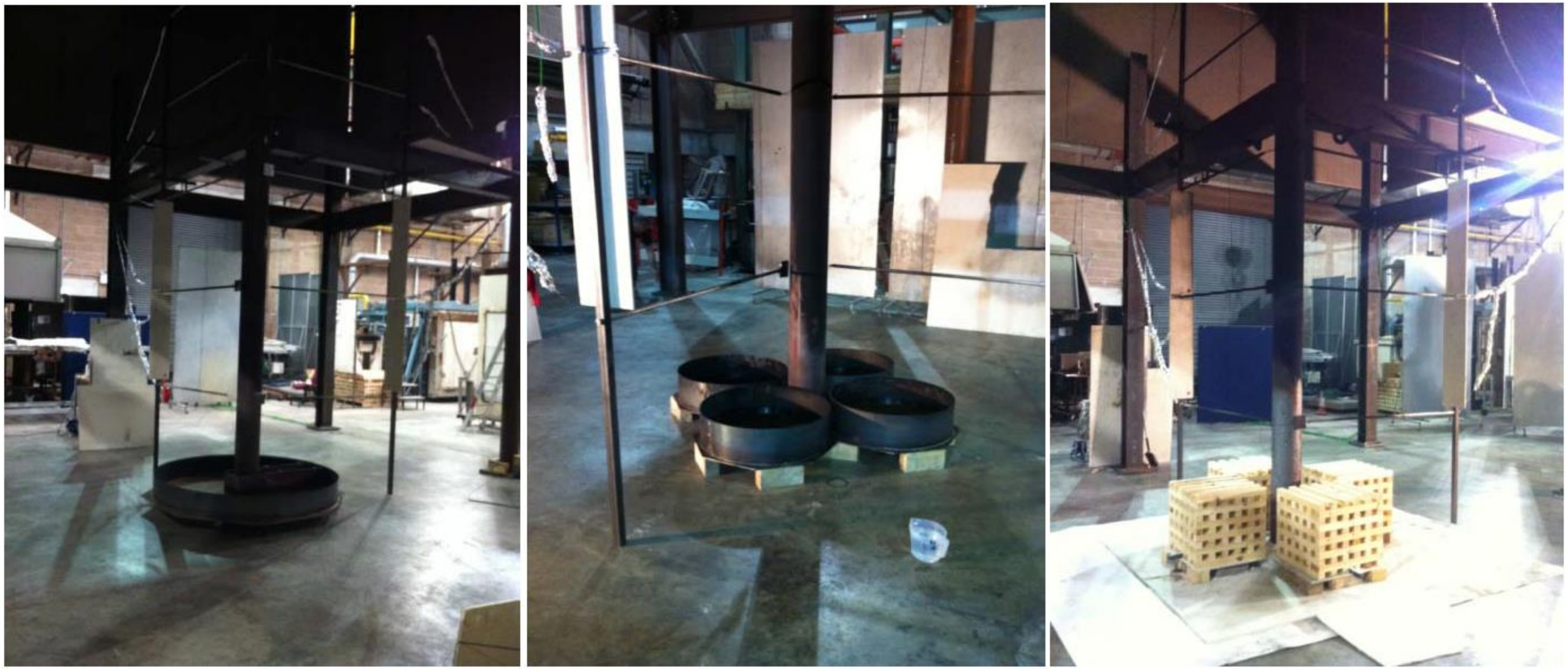
Column with no ceiling



Column with ceiling

LOCAFI Method

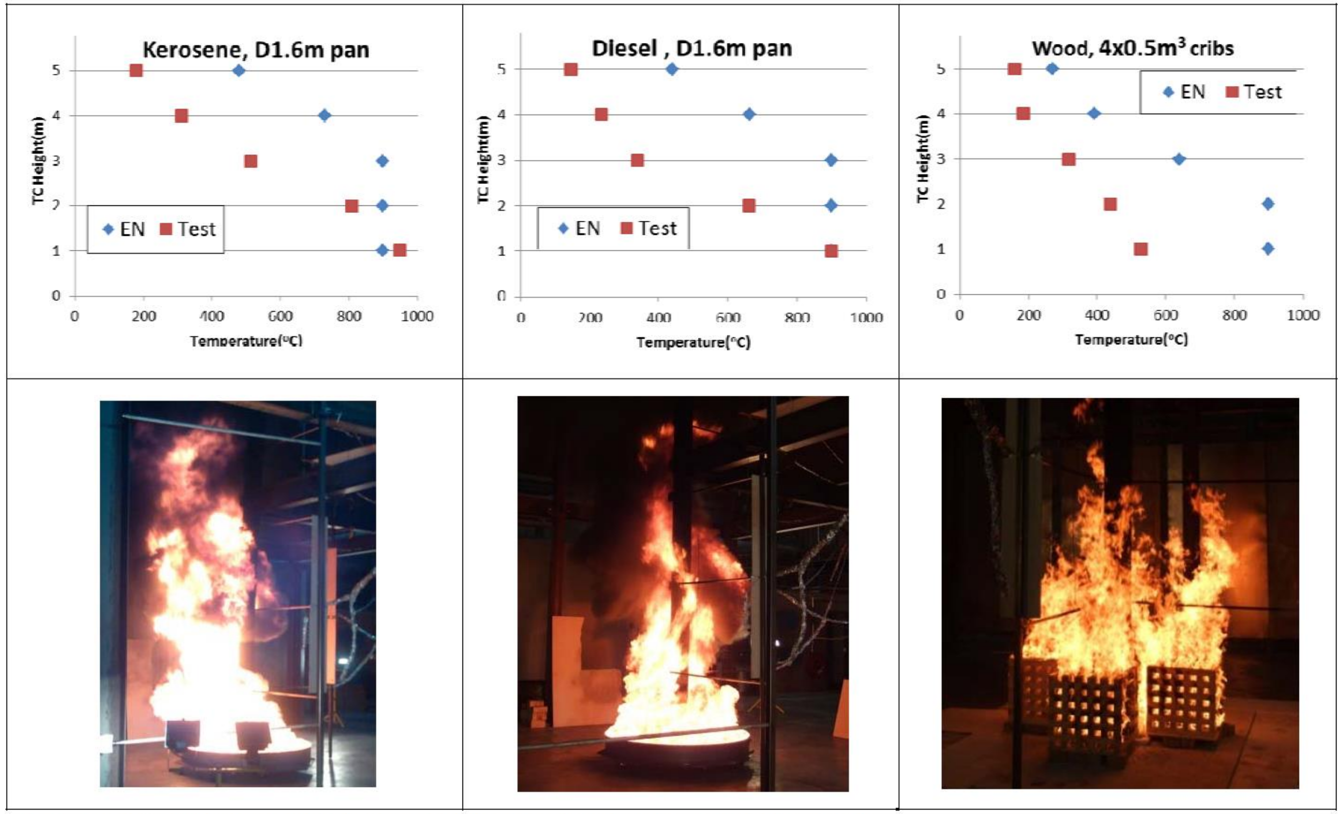
Experimental tests



LOCAFI Method

Experimental tests

5M	479	179	440	146	157	-	139	-	271	159



* TC are located on steel column, middle of 4 wood cribs. (Test No. O14)

Figure 2-30 : Comparison between temperatures measured experimentally (Test) and predicted by use of EN for 3 different types of fuel

LOCAFI Method

Development and calibration of a CFD numerical model and parametric analyses.

Since it is impossible to test every possible situation, an extensive study using the Fire Dynamic Simulator software was carried out. It made it possible to validate the method.

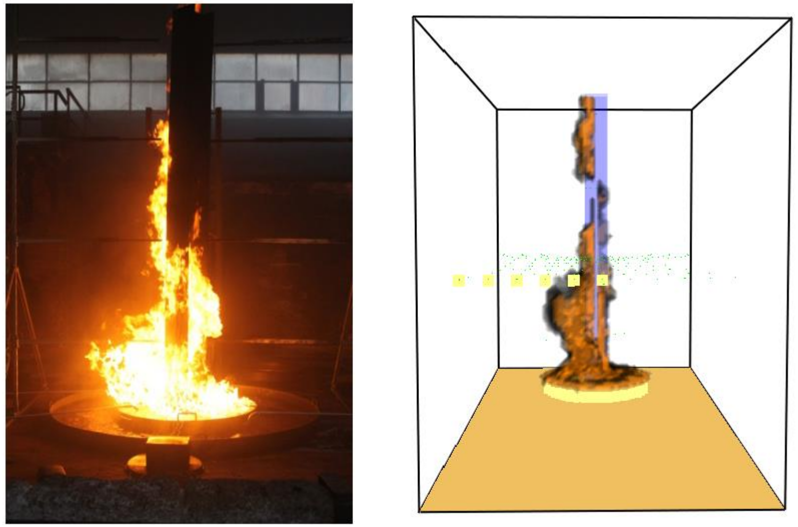


Figure 2-34 : ULG T14 Experimental test(left) – Numerical simulation (right)

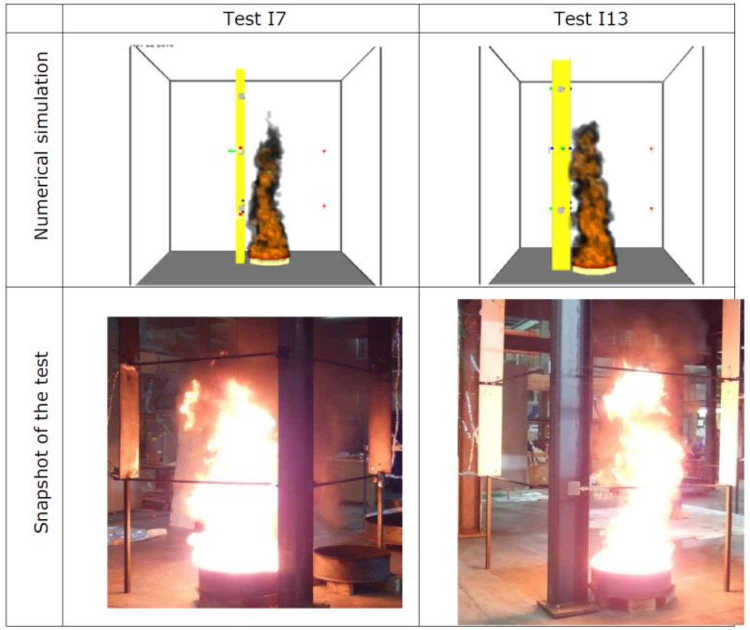


Figure 2-51 : Flame shape for tests I7 and I13 of group 1

LOCAFI Method

Development of the analytical method

The aim of this research being to develop an analytical method, the various tests and numerical analysis have made it possible to develop it.

After analysis, the hearth is represented by a circle of equivalent diameter and with a flame modeled by a cone which in the simplified method is modeled by a stack of cylinders of decreasing diameter.

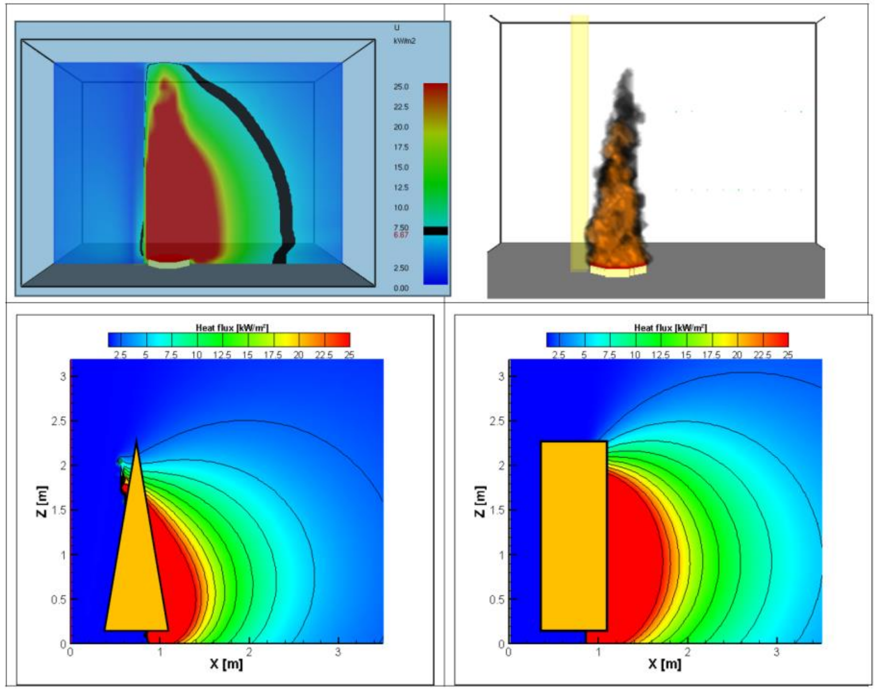


Figure 2-67 : Integrated intensity (top left), flame shape (top right), heat flux with a conical flame, (bottom left), heat flux with a cylindrical flame (bottom right)

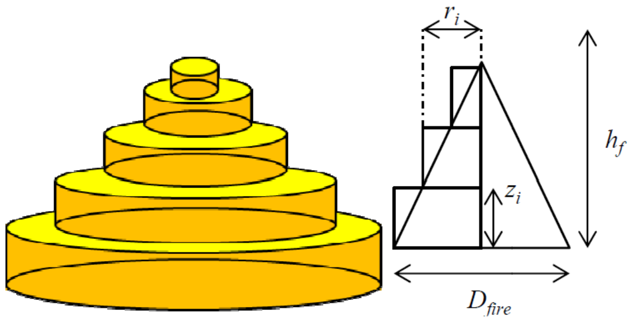


Figure 2-75 : Solid flame shape (left) and geometrical details (right)

LOCAFI Method

Development of the analytical method

All that remains is to determine the heat flux that the column receives using geometric formulas by dividing it into elements and using view factors.

Configuration factor between an infinitesimal plane and a finite cylinder

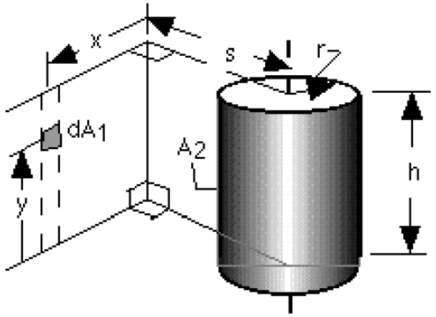


Figure 2-78 : Configuration cylinder – plane element

With $S = s/r, X = x/r, Y = y/r, H = h/r, A = X^2 + Y^2 + S^2, B = S^2 + X^2, C = (H - Y)^2$

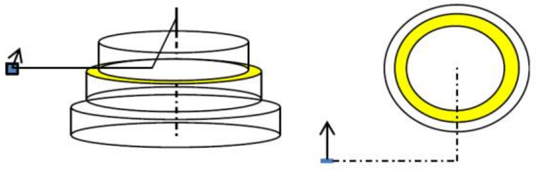


Figure 2-85 : Ring modelling (top view)

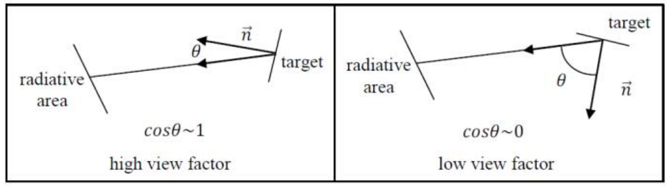


Figure 2-86 : Influence of the orientation of the target

The full method is available in SAFIR and ANSYS software, while the simplified method is available with Ozone software.

Bibliography and sources

Bibliography and sources

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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
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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

Fire Safety & Engineering SA