Evaluation of Structural Fire Performance. Today and Tomorrow

Jean-Marc Franssen, Thomas Gernay, François Hanus & Christophe Peigneux
jm.franssen@ulg.ac.be

Content

- Modelling of 3D structures
- Joints in steel structures
- Spalling in concrete structures
- Cellular beams
- Tensile membrane action

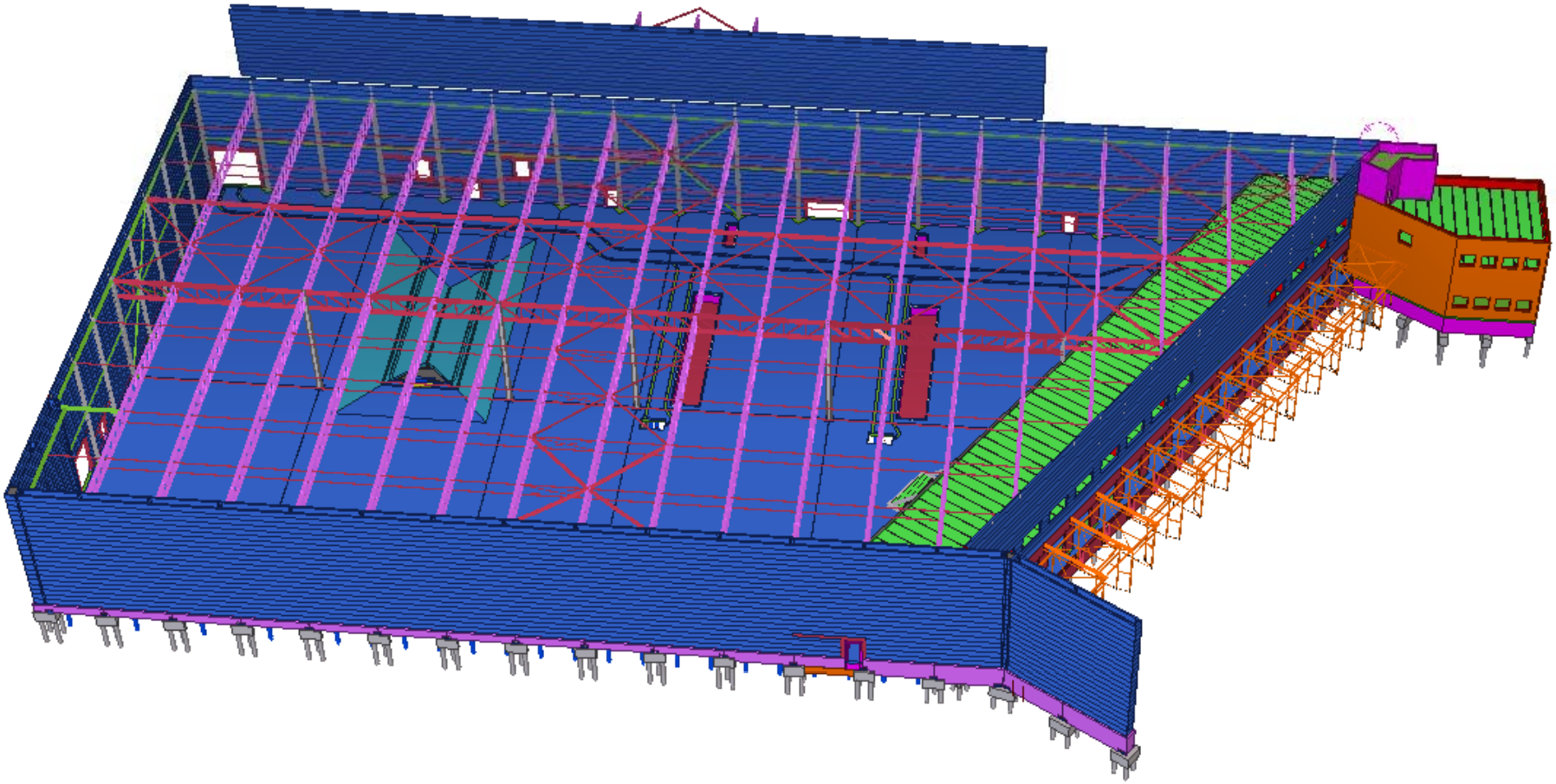
Modelling of 3D structures

The detailled 3D discretisation and analysis of a complex structure made of numerous bars is not practically feasible.

Solution: series of uncoupled sub-structure analyses

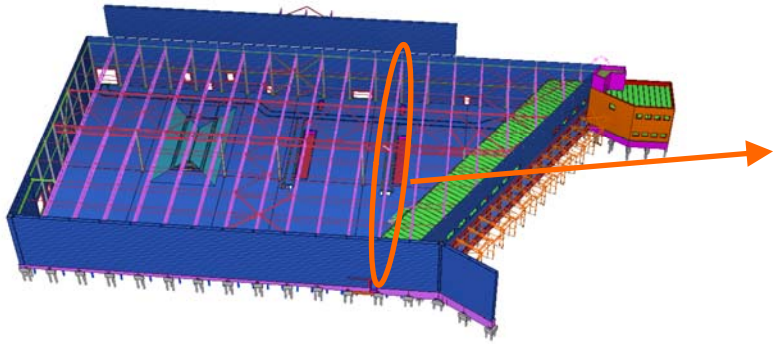

HYUNDAI

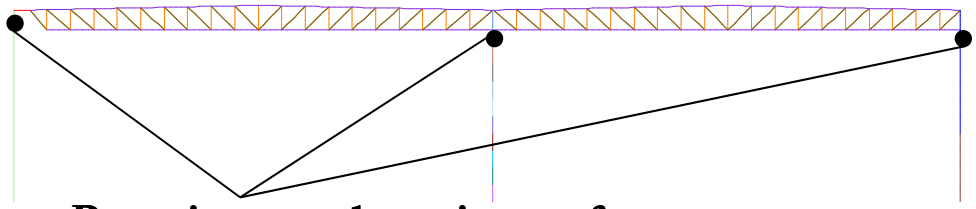
Modelling of 3D structures



Modelling of 3D structures

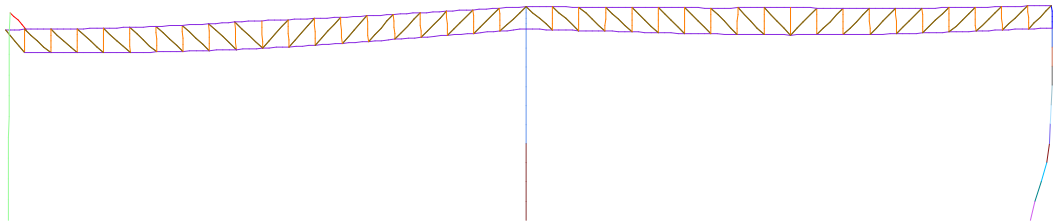
Structural analysis of the secondary frame





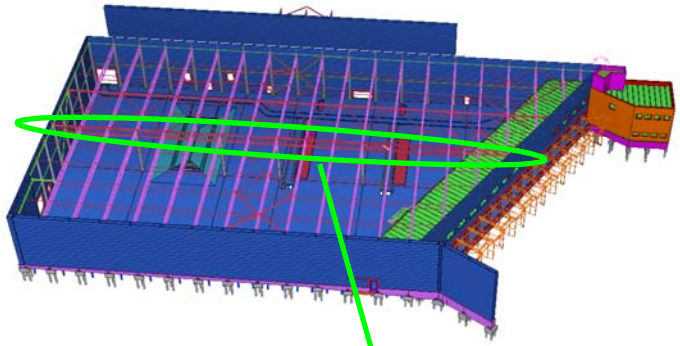
Reactions to the primary frames

Failure Mode of the secondary frame

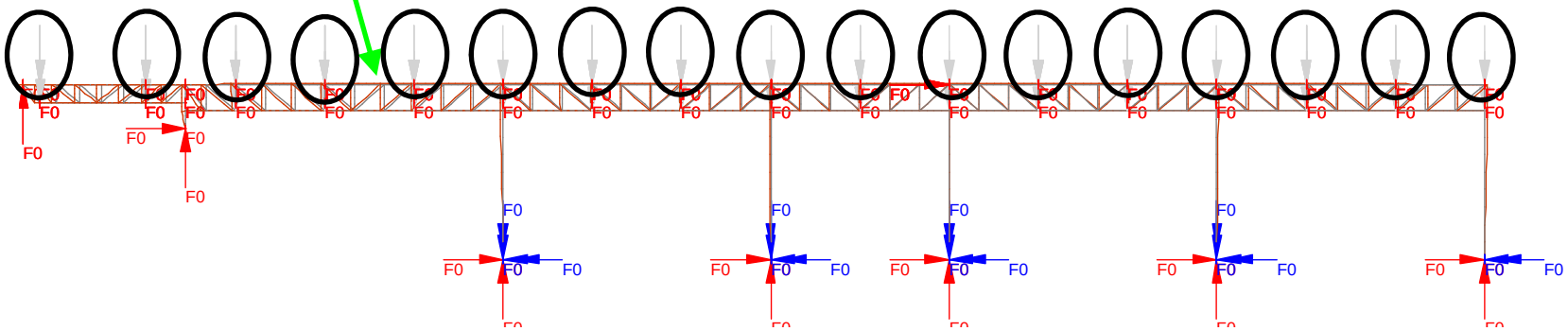


Modelling of 3D structures

Application of reaction to the primary frames

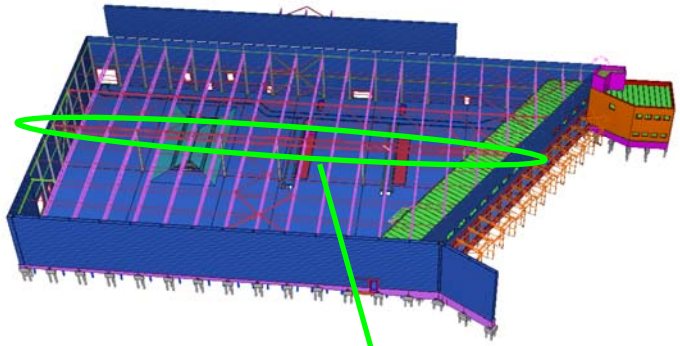


Reactions from secondary frames

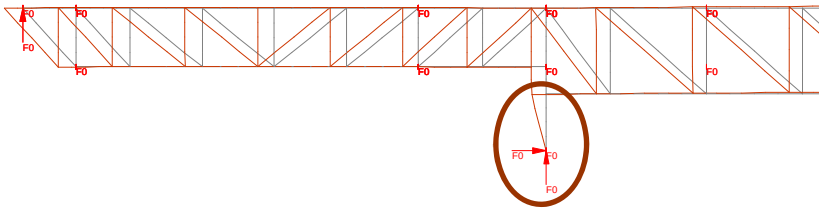


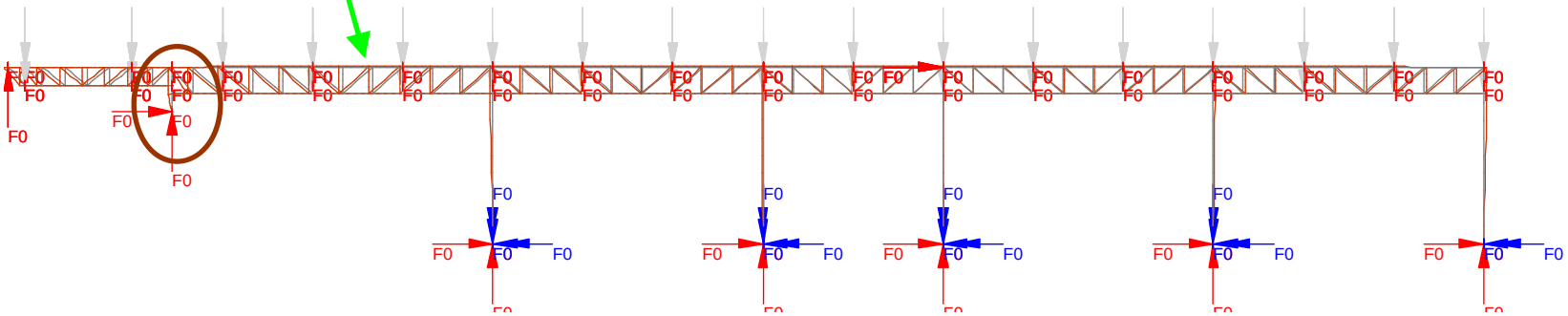
Modelling of 3D structures

Application of reaction to the primary frames

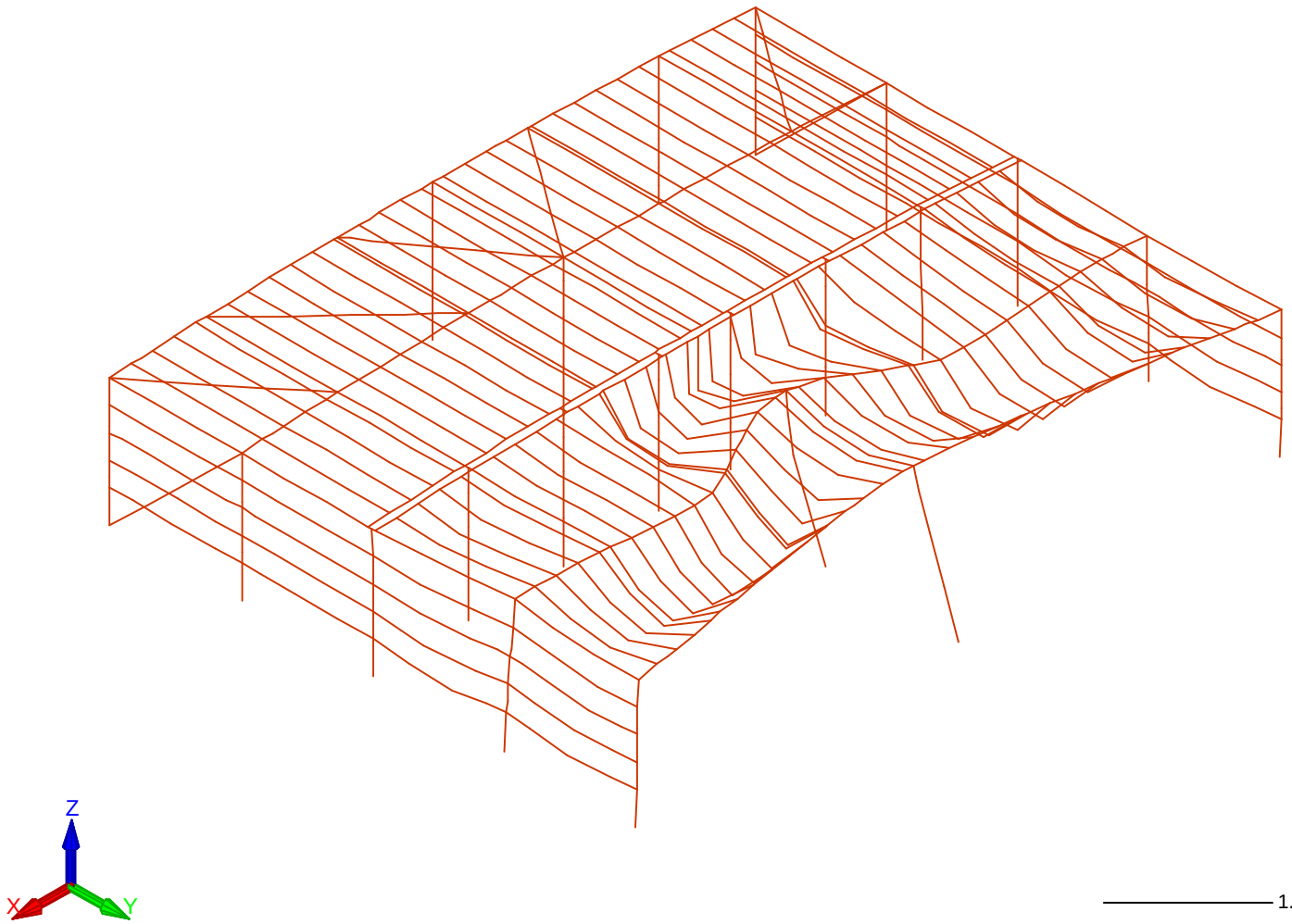


Failure Mode of the primary frame





Test « FLUMILOG », courtesy INERIS, France



Diamond 2009.a.5 for SAFIR

FILE: Modelo_Def_3
NODES: 2624
BEAMS: 940
TRUSSES: 0
SHELLS: 0
SOILS: 0

DISPLACEMENT PLOT (x 1)

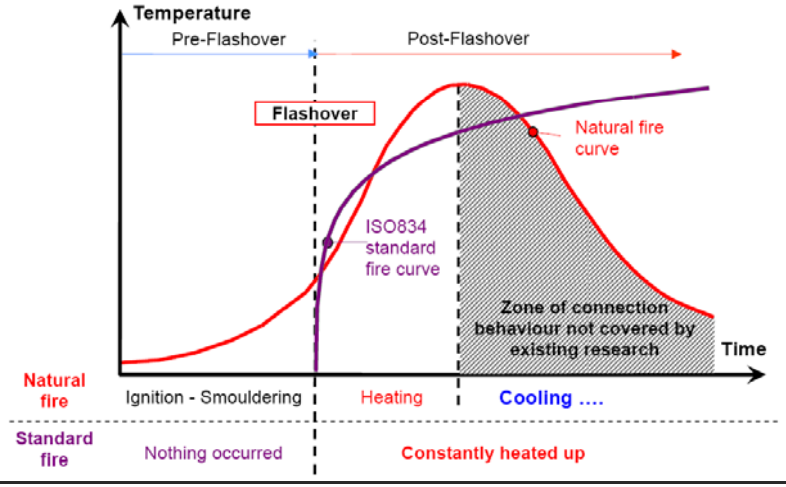
TIME: 739.0464 sec

Joints in steel structures

Introduction to the problem

Until recently, the behaviour of steel joints under fire conditions has not been investigated because :

- **The fire resistance of steel structures is usually calculated under fire curves with no cooling phase.**

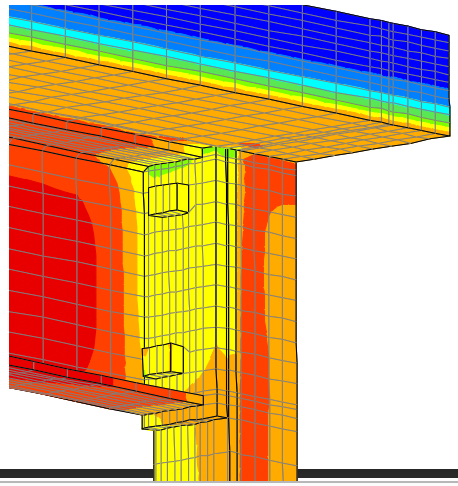


Joints in steel structures

Introduction to the problem

Until recently, the behaviour of steel joints under fire conditions has not been investigated because :

- **Due to the presence of more material, temperature in joint is lower than in the connected members.**



Joints in steel structures

Introduction to the problem

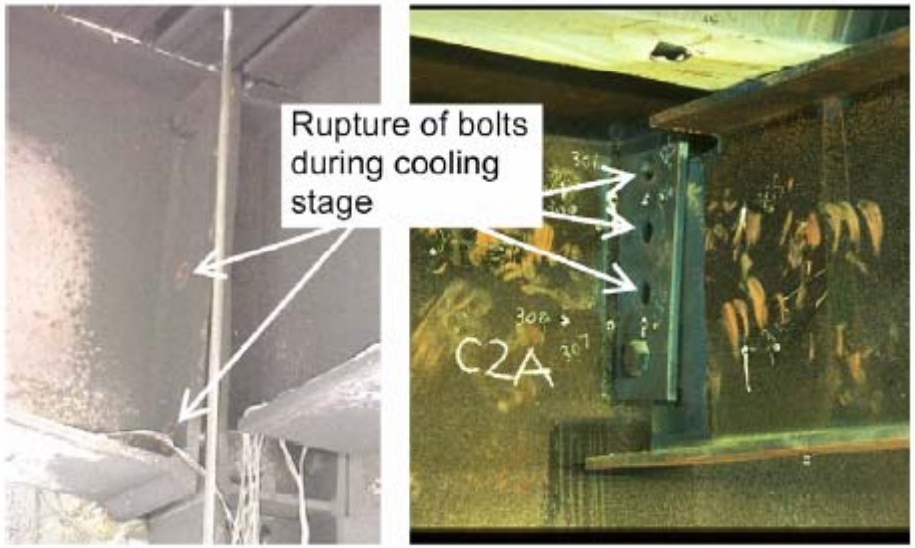
Until recently, the behaviour of steel joints under fire conditions has not been investigated because :

- **The joints are usually designed to be more resistant than the connected members at room temperature.**

Joints in steel structures

Introduction to the problem

However, failures in joint components have been observed experimentally during the cooling phase of natural fires :

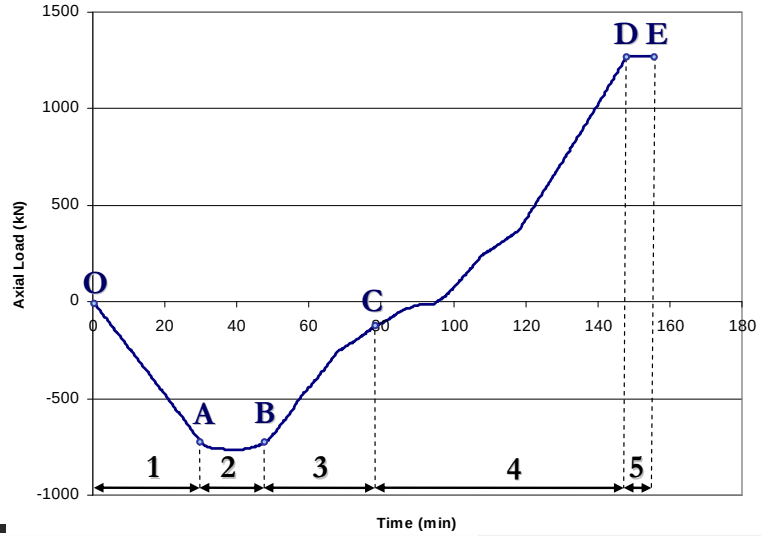


Joints in steel structures

Introduction to the problem

Joint failures occurs during the cooling phase of natural fires because :

- **During the cooling phase, large tensile forces are generated in axially restrained beams**

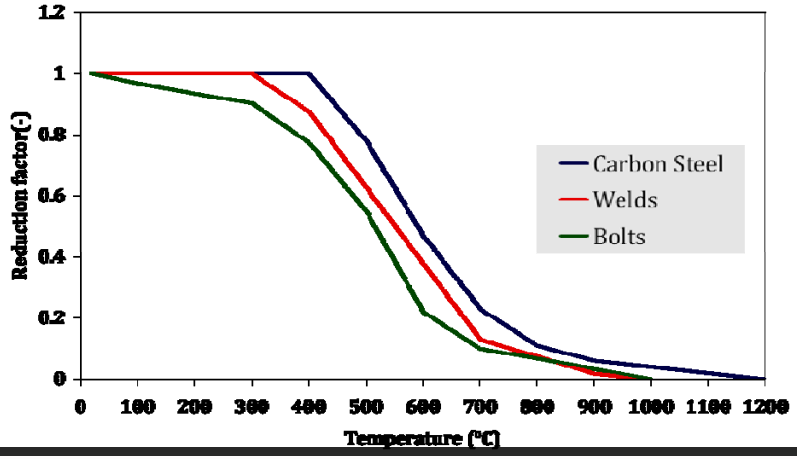


Joints in steel structures

Introduction to the problem

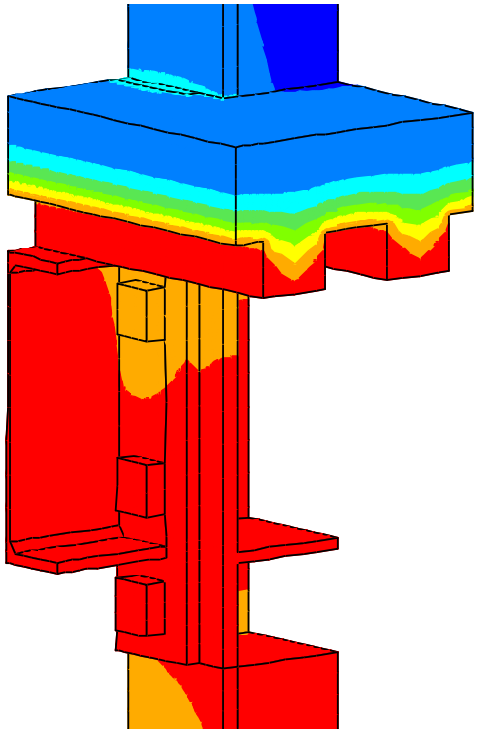
Joint failures occurs during the cooling phase of natural fires because :

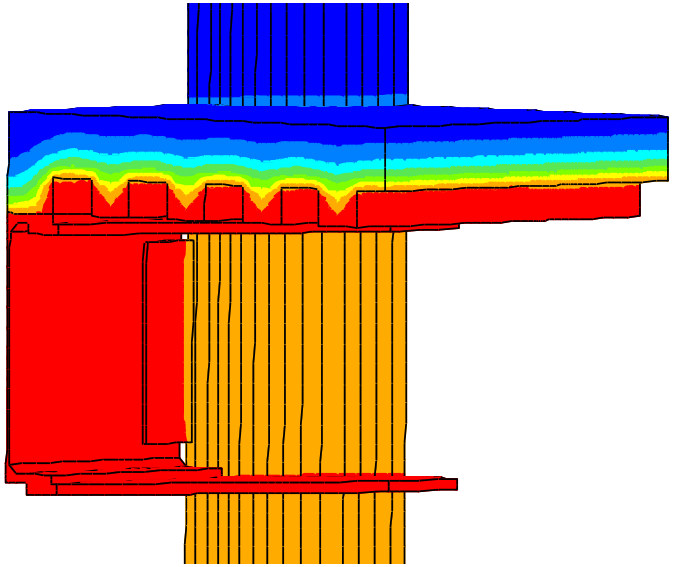
- **The resistance of bolts and welds reduces quicker than carbon steel at elevated temperatures and is not reversible during the cooling phase (EN 1993-1-8)**



Joints in steel structures

Numerical Modelling of Joints – Thermal analyses

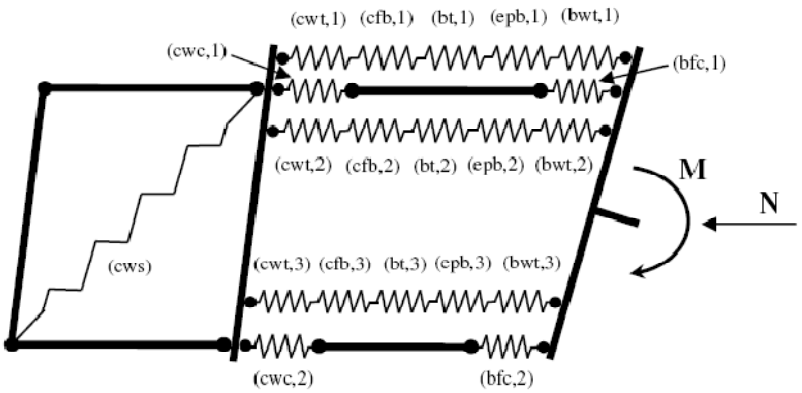


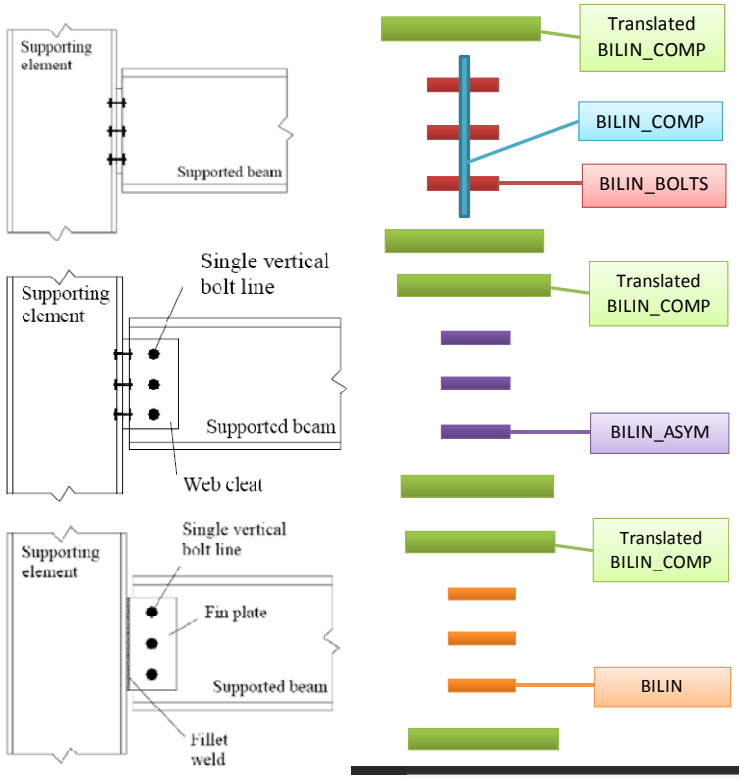


Joints in steel structures

Numerical Modelling of Joints – Structural Analyses

- **Fibre Models based on the Component Method**



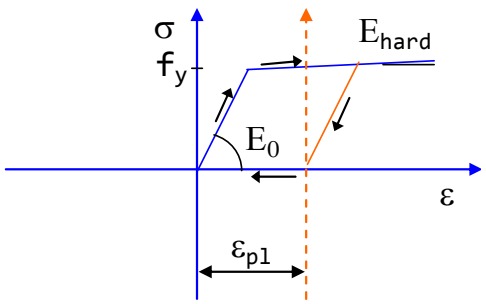


Joints in steel structures

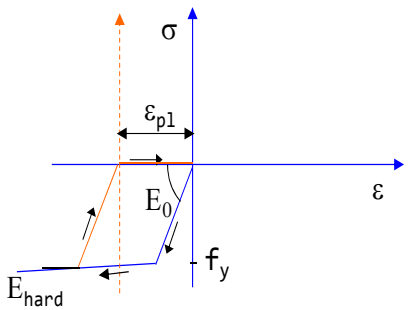
Numerical Modelling of Joints

- **Material Laws working in tension/compression or asymmetric**

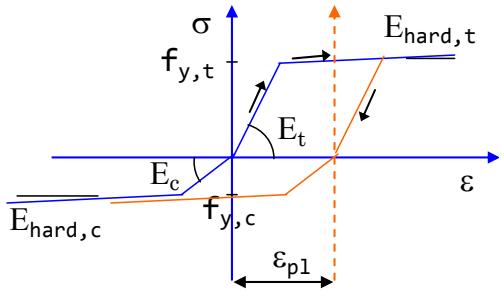
Tension



Compression



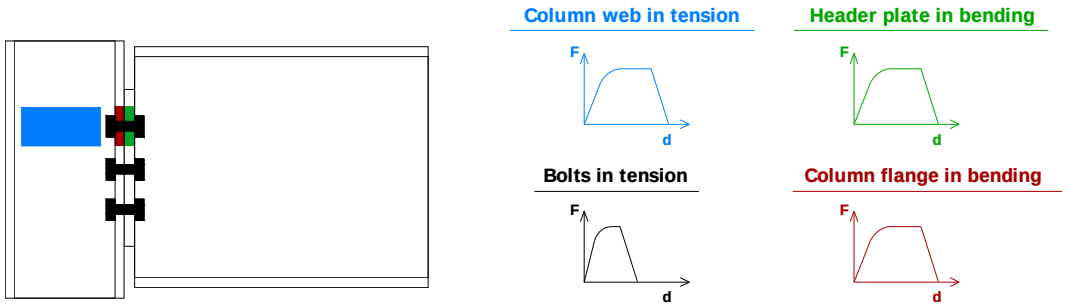
Asymmetric

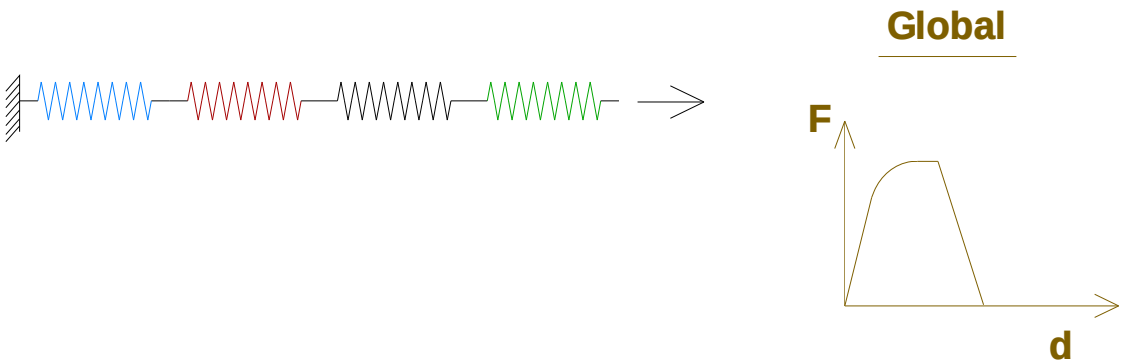


Joints in steel structures

Numerical Modelling of Joints

- **Laws with descending branch to include the risk of failure**

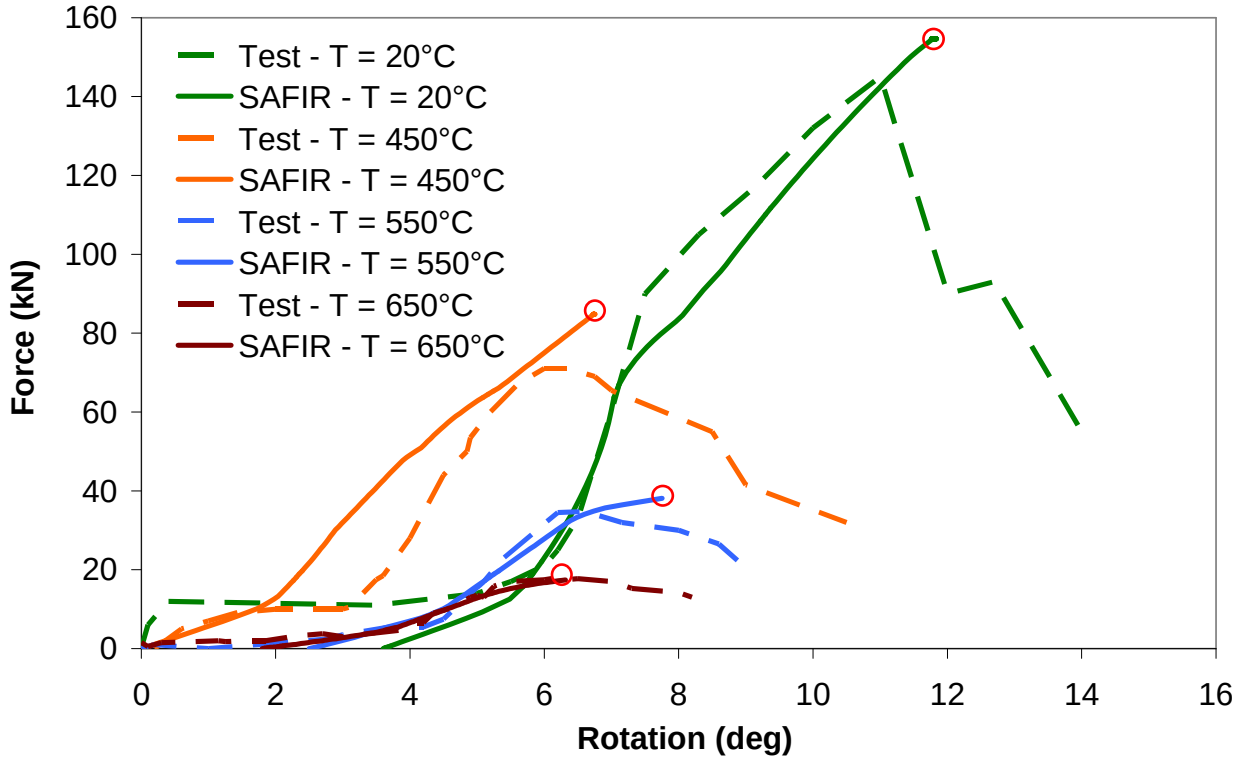




Joints in steel structures

Tests performed at University of Sheffield

Comparisons between experimental and numerical rotations

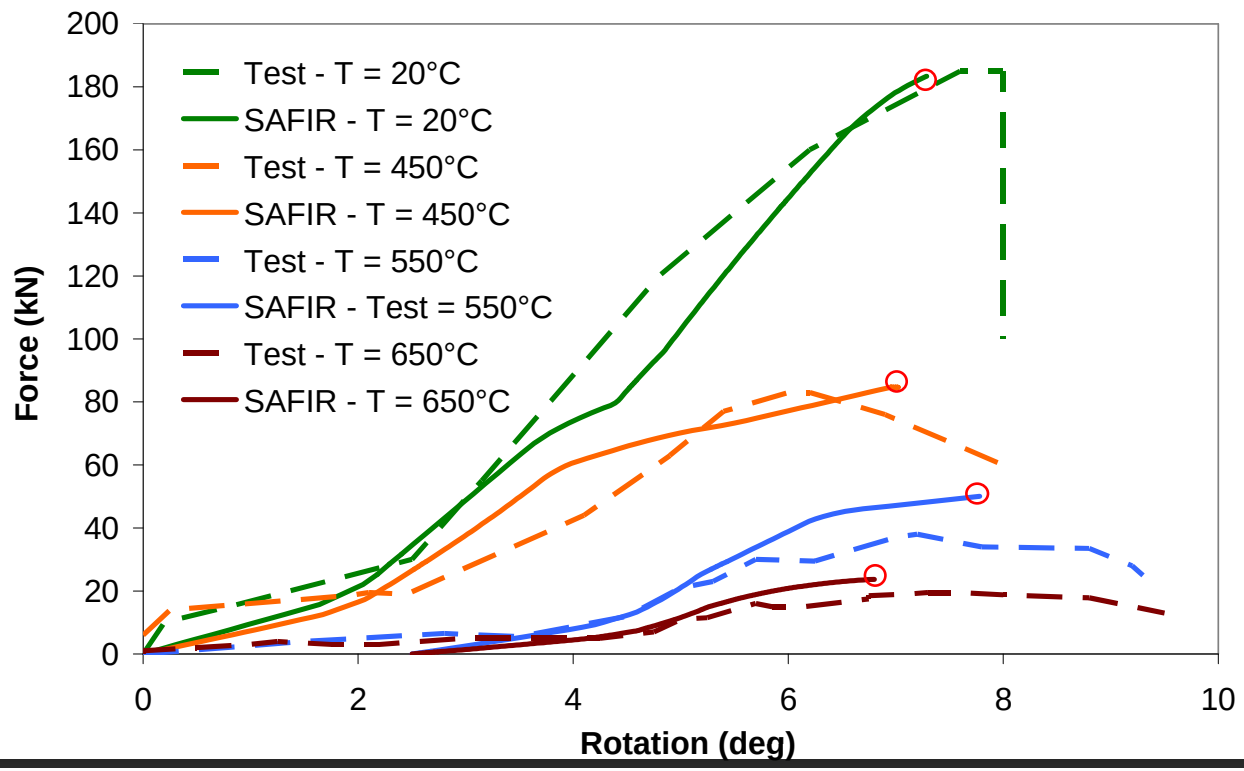


$\alpha = 55°$

Joints in steel structures

Tests performed at University of Sheffield

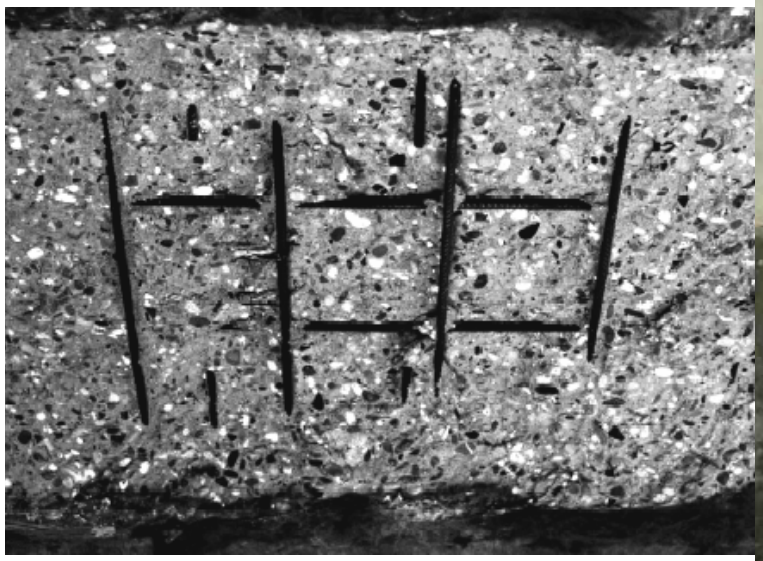
Comparisons between experimental and numerical rotations



$\alpha = 35°$

Spalling in concrete structures

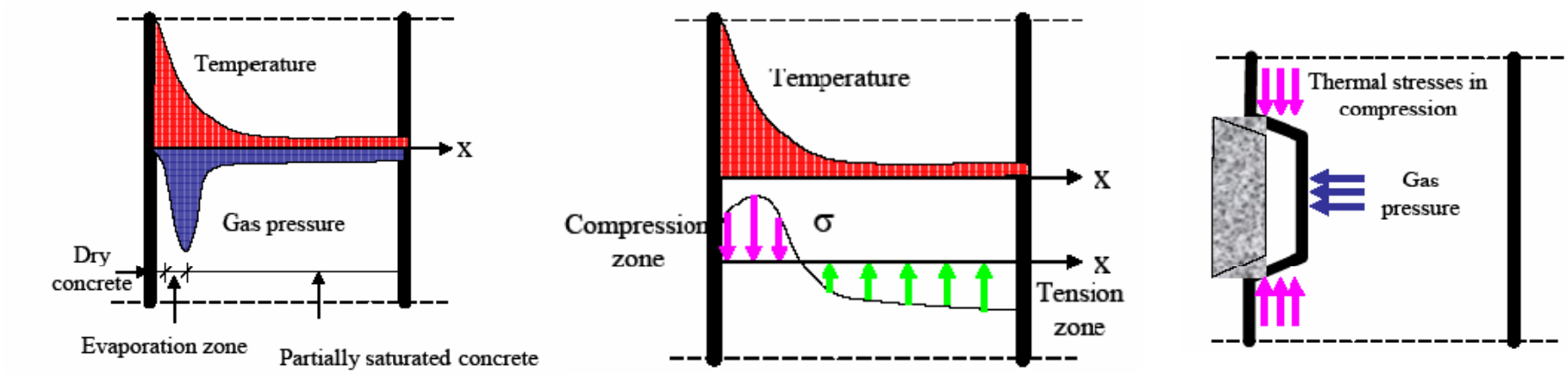
Under high temperatures, concrete layers spalls



Spalling in concrete structures

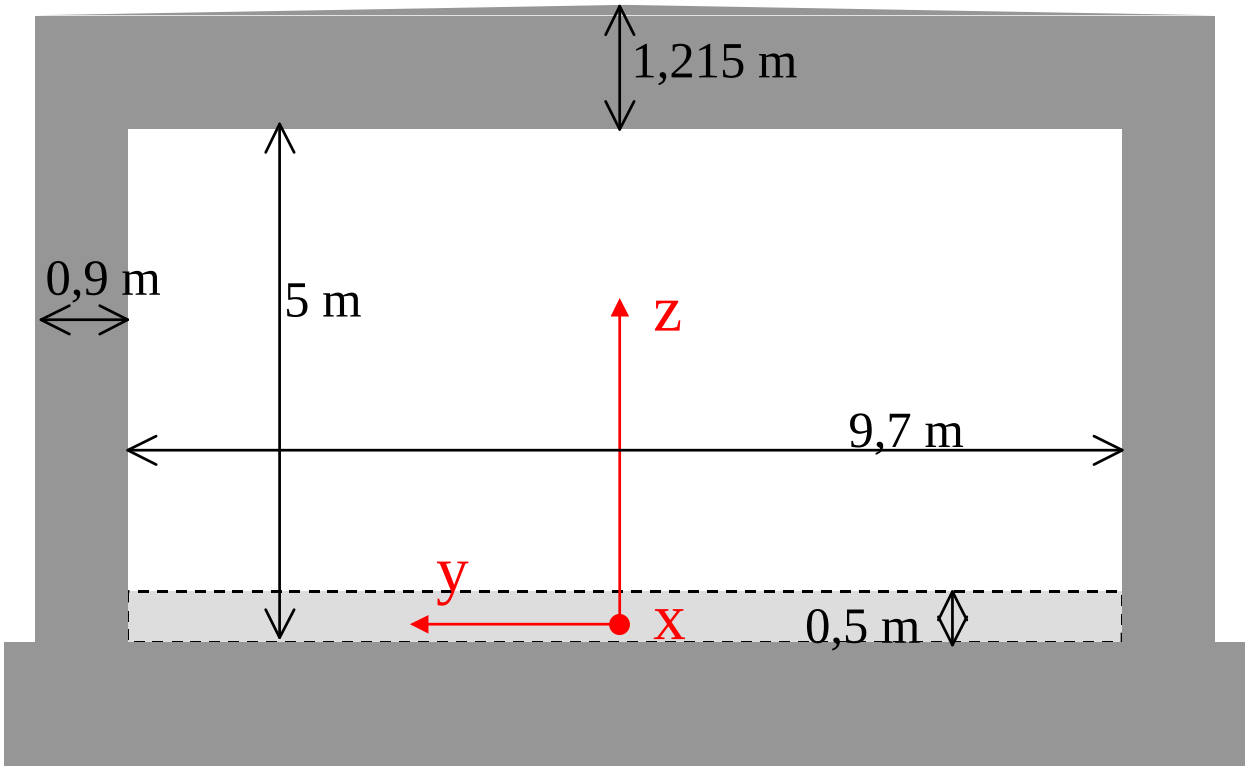
Introduction to the problem

Under high temperatures, concrete layers spalls



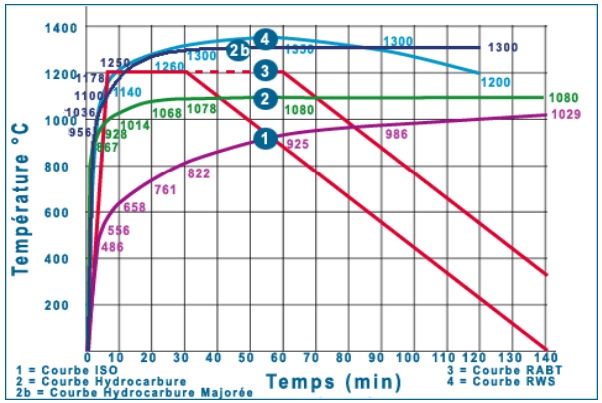
Spalling in concrete structures

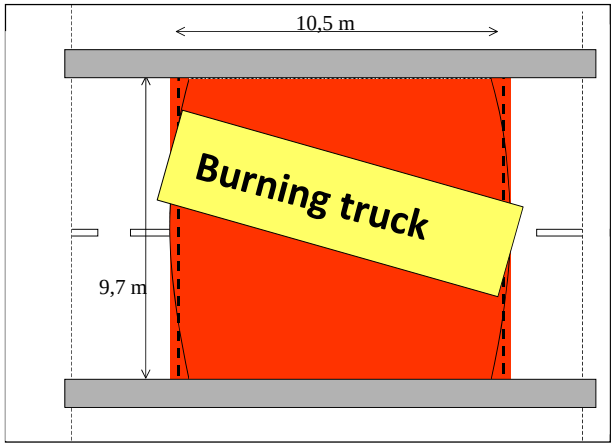
Analysed Structure

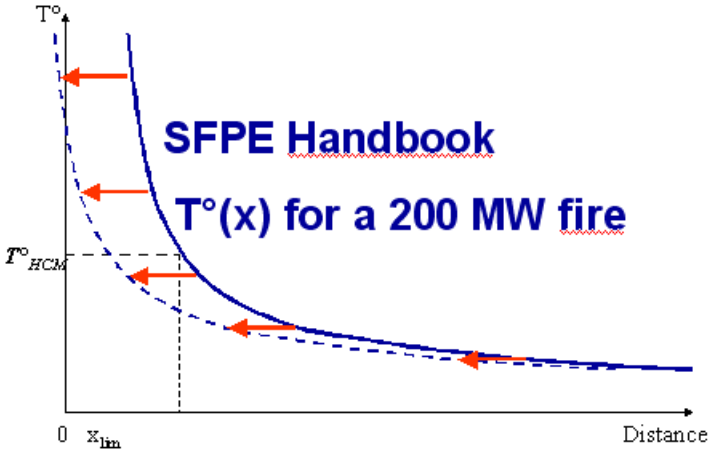


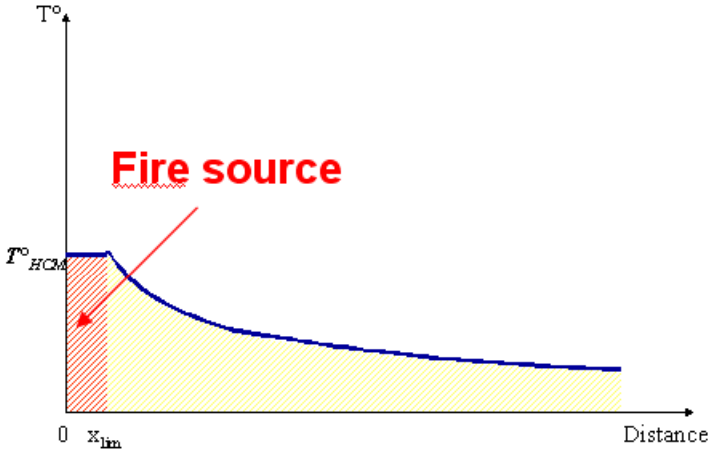
Spalling in concrete structures

Fire Scenario : Courbe HCM



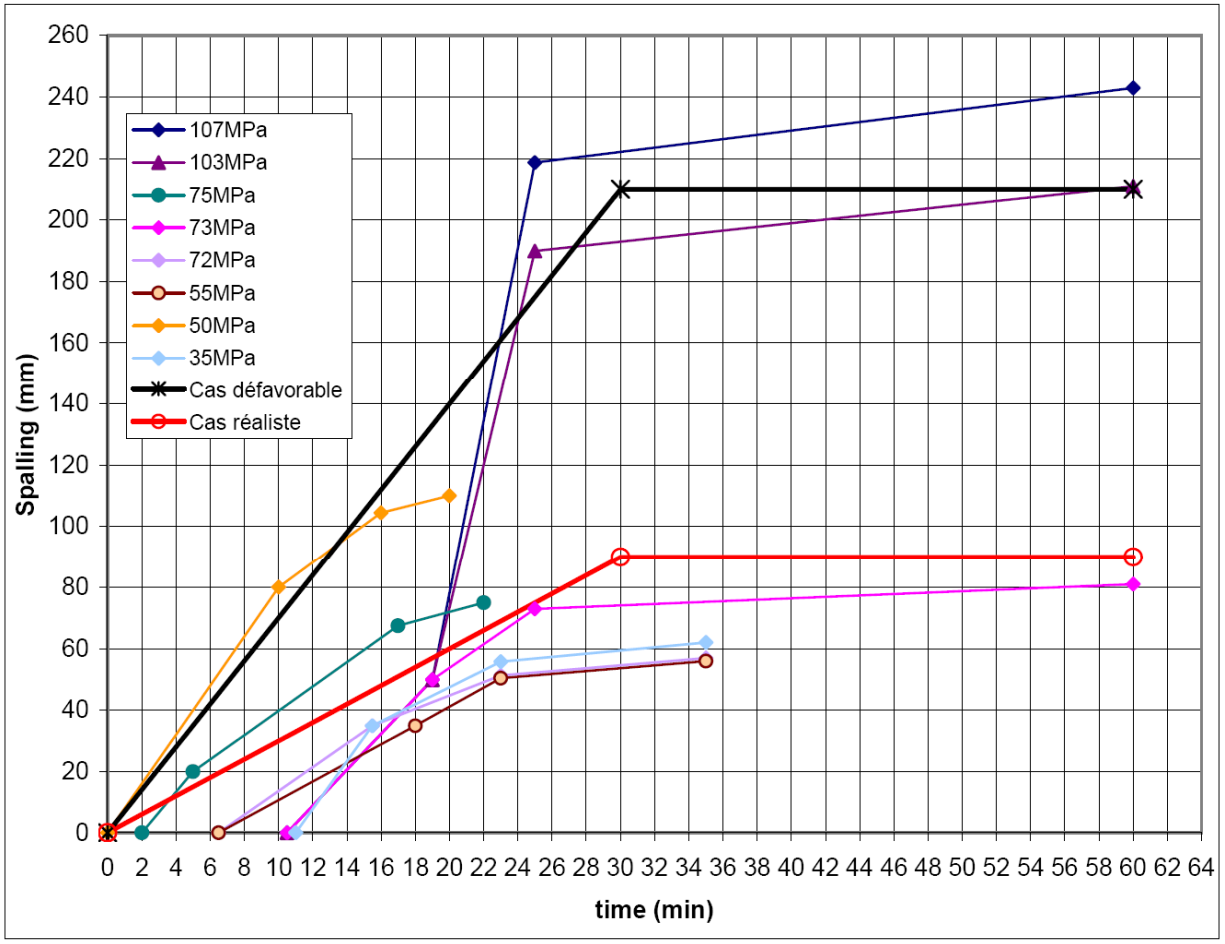






Spalling in concrete structures

Results of tests and Assumptions



Unfavour. Case :

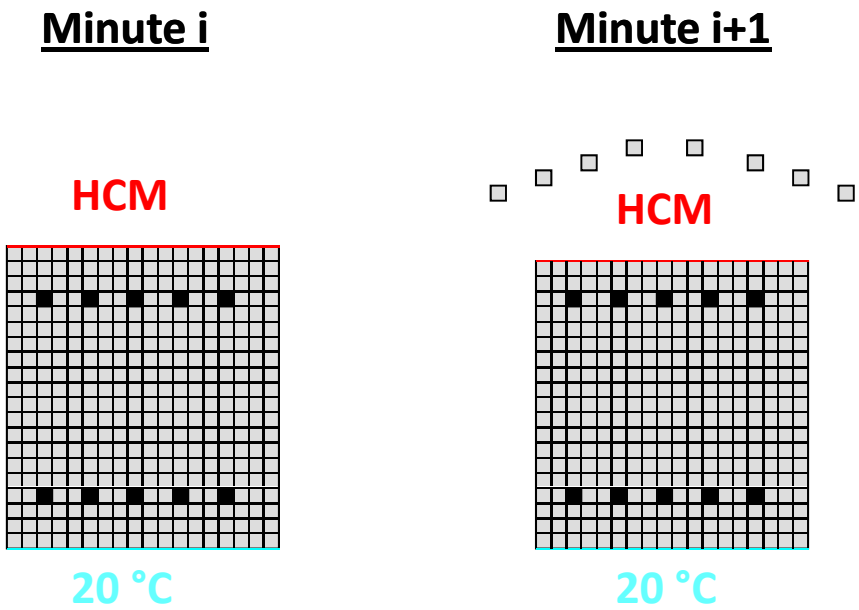
[redacted]

Realistic Case :

3 mm/min during 30 min

Spalling in concrete structures

Integration of spalling



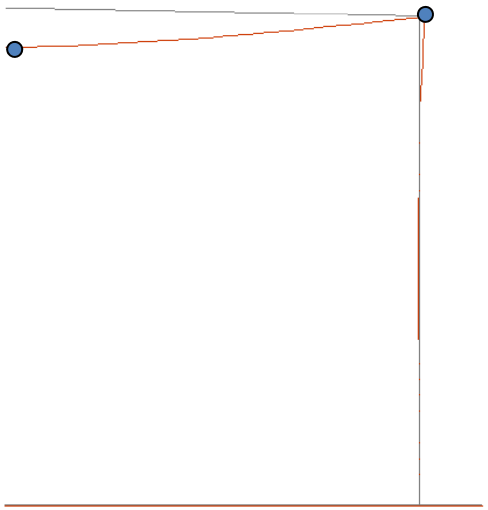
3 or 7 mm-thick concrete layer

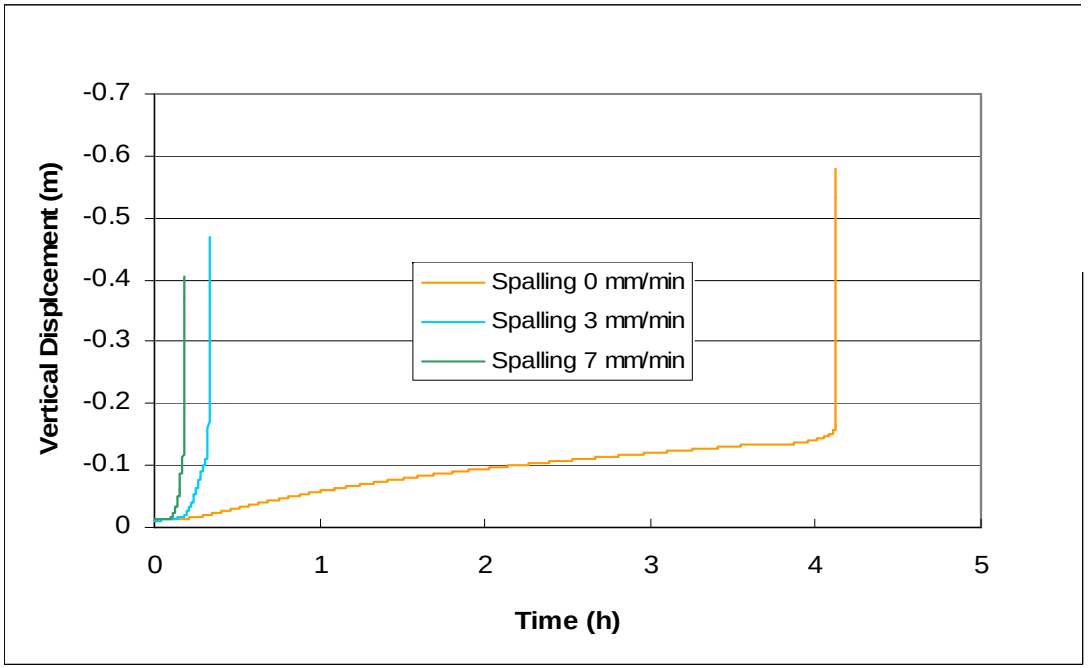
Rebars are removed simultaneously with concrete of the same level

Spalling in concrete structures

Results

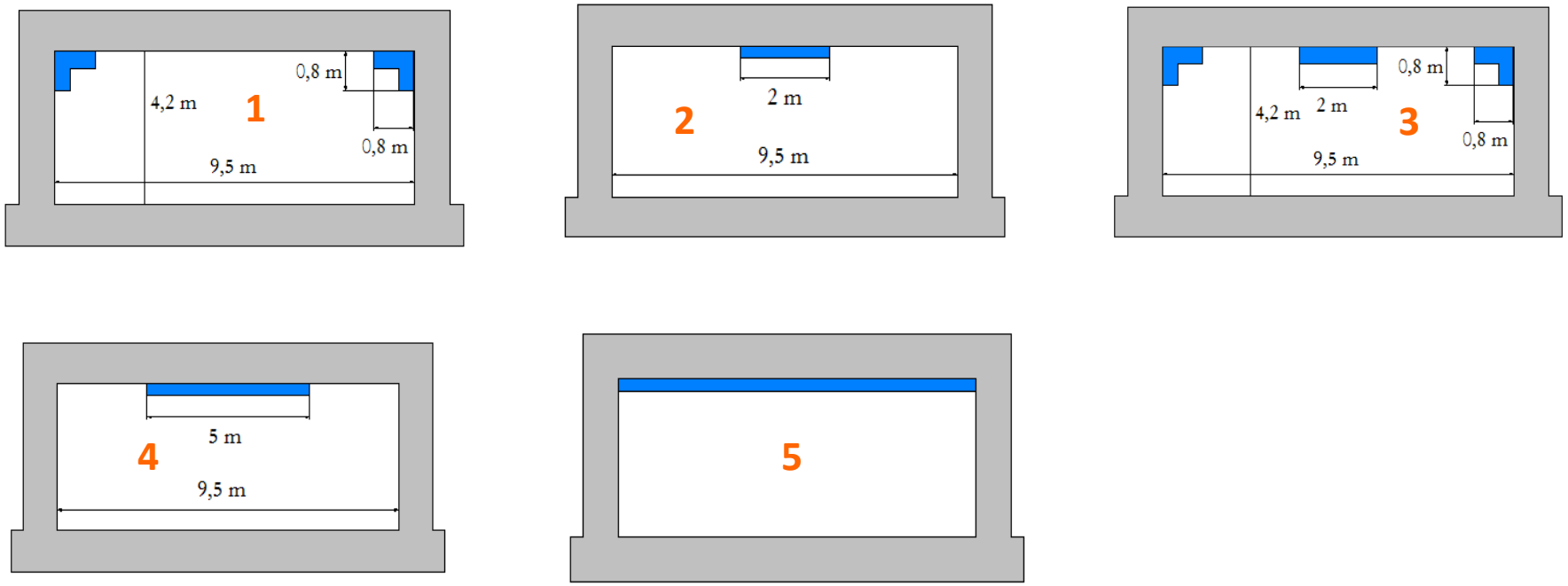
Failure Mode with & without spalling





Spalling in concrete structures

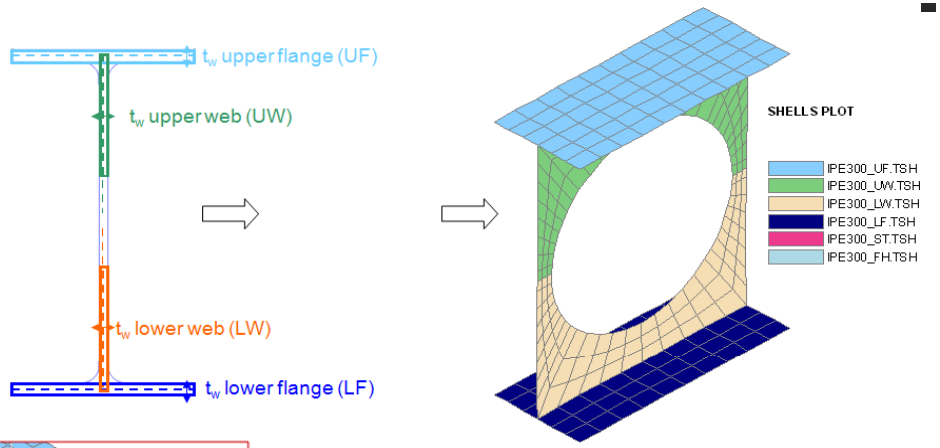
Fire Resistance with partial protection

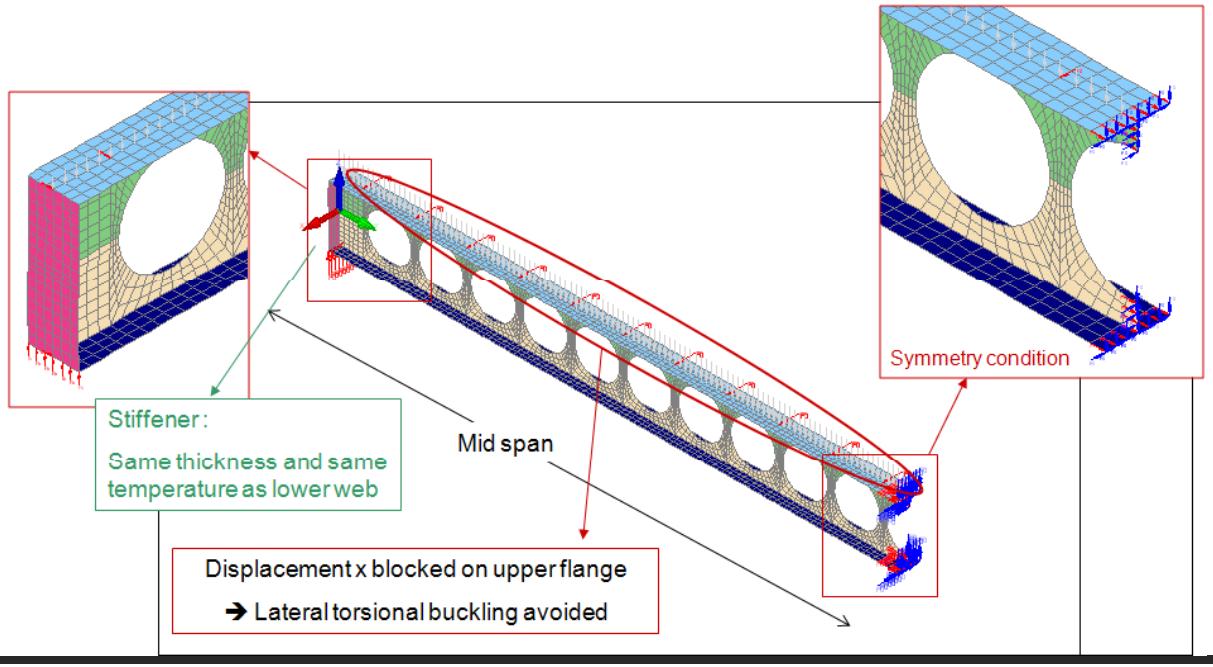


Cellular beam – steel beam

Model

- 4-node shell finite elements

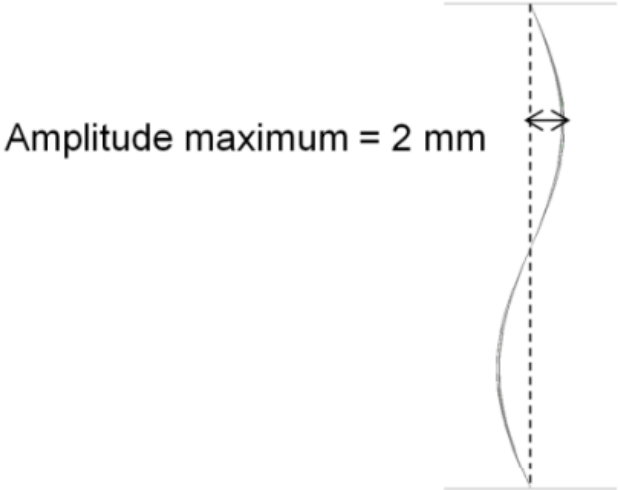


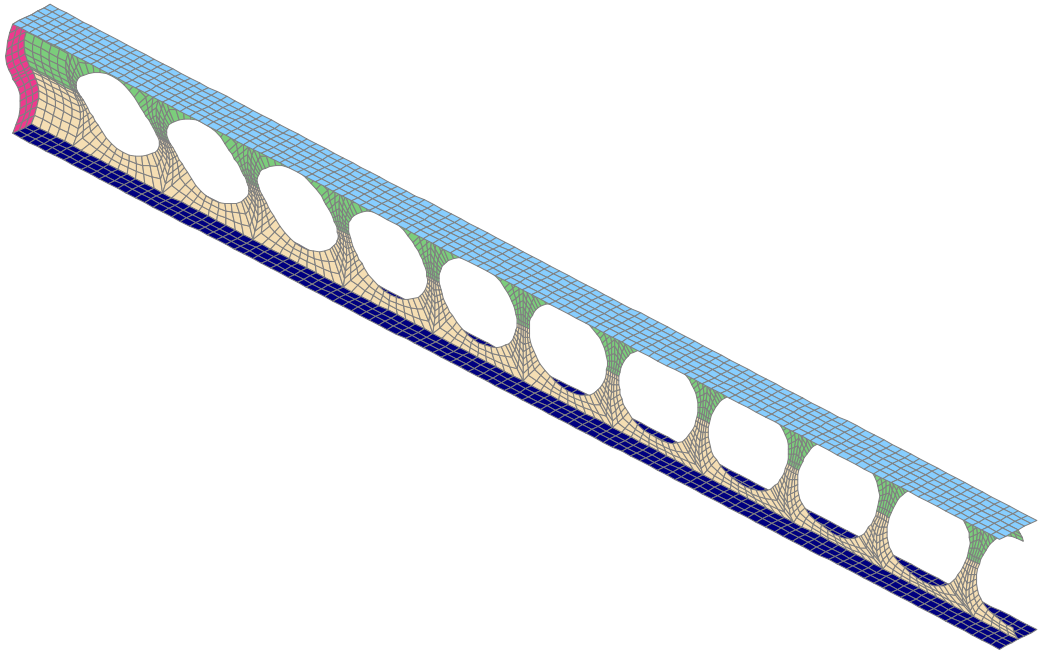


Cellular beam – steel beam

Initial deformation

- To obtain local buckling
- Sine curve on the height of the profile
- Cosine curse on the length of the beam

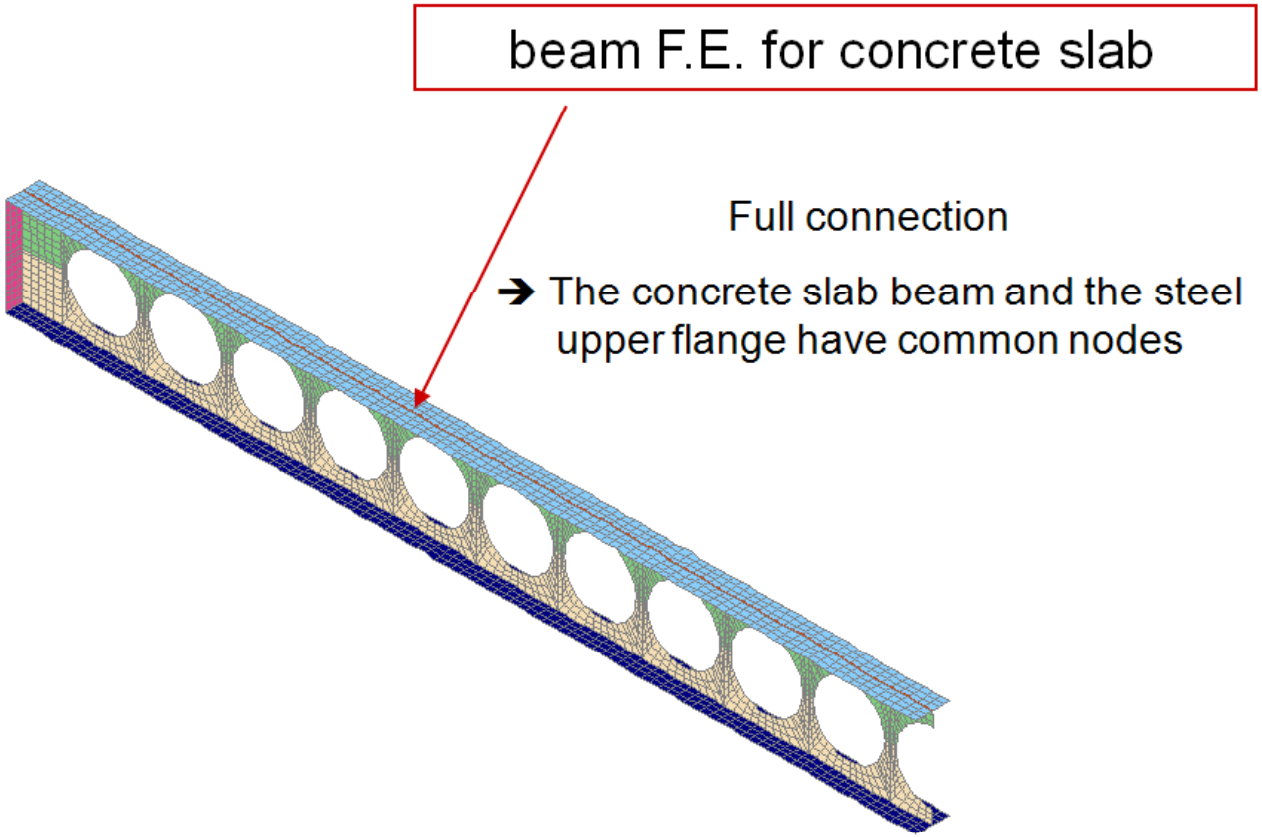




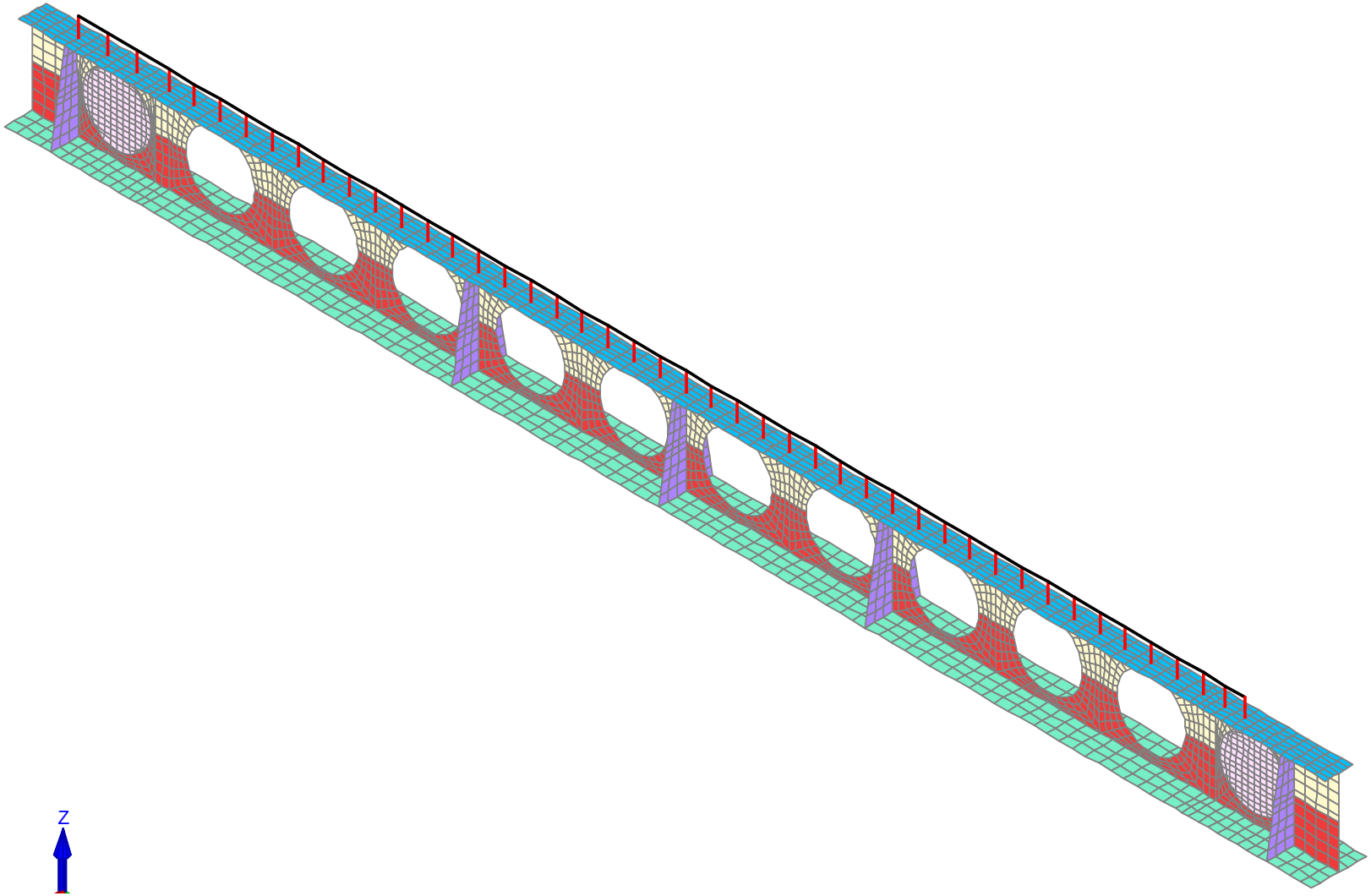
Cellular beam - Composite beam – Full connection

Model

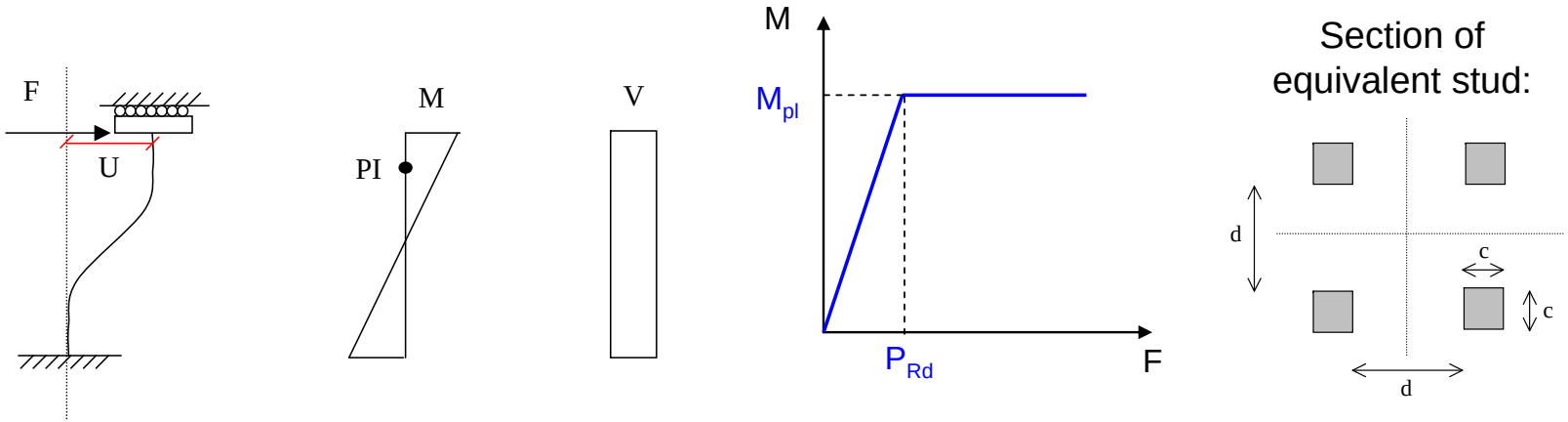
- 4-node shell finite element for the steel profile
- Beam element for the concrete slab



Cellular beam - Composite beam - Partial connection



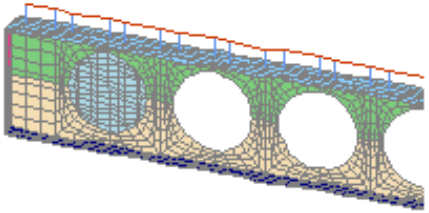
Stud model

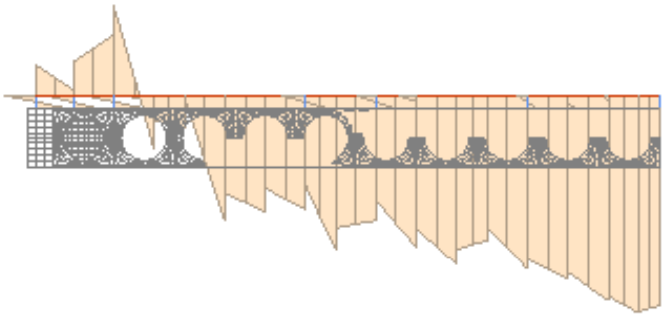


- Model 1: the number of equivalent studs is equal to real number of studs
- Model 2: an equivalent stud is placed on each node of the upper steel flange
- Model 3: idem than model 2 but the equivalent stud section is numerically improved.

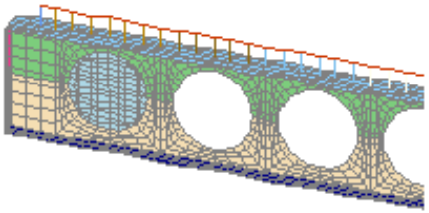
Stud model

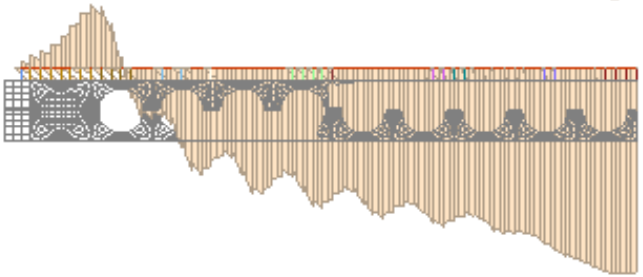
- Stud model 1



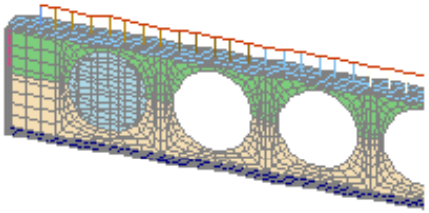


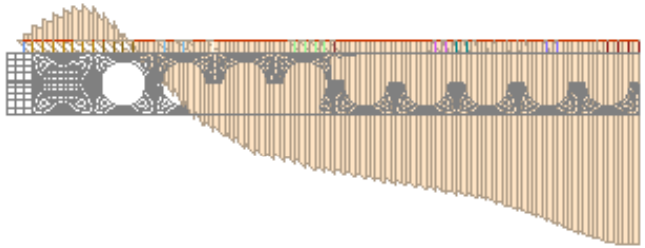
- Stud model 2



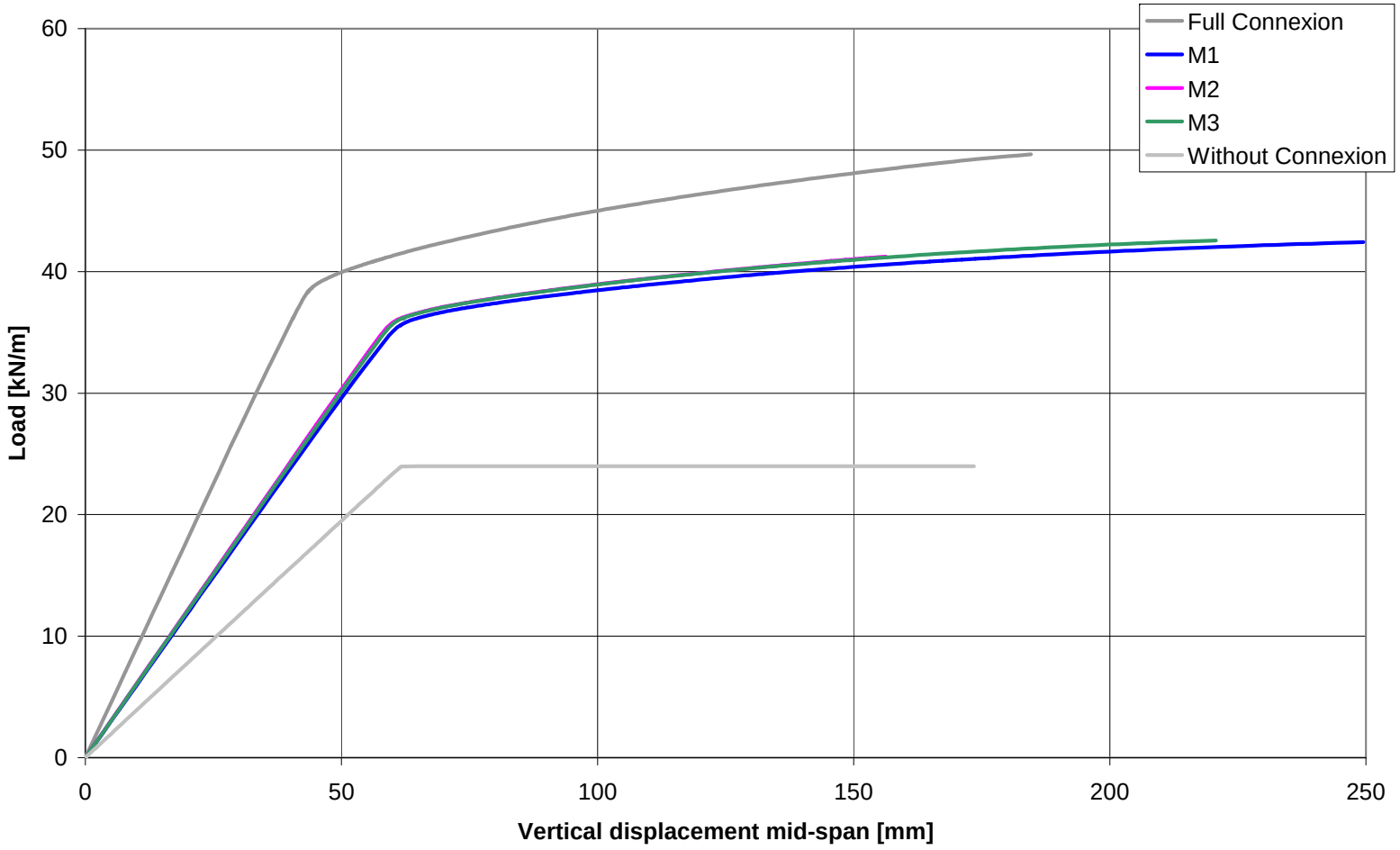


- Stud model 3

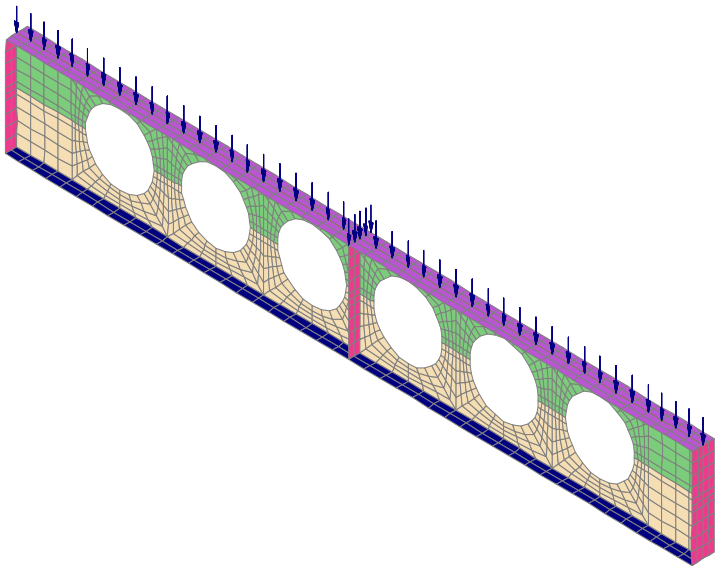


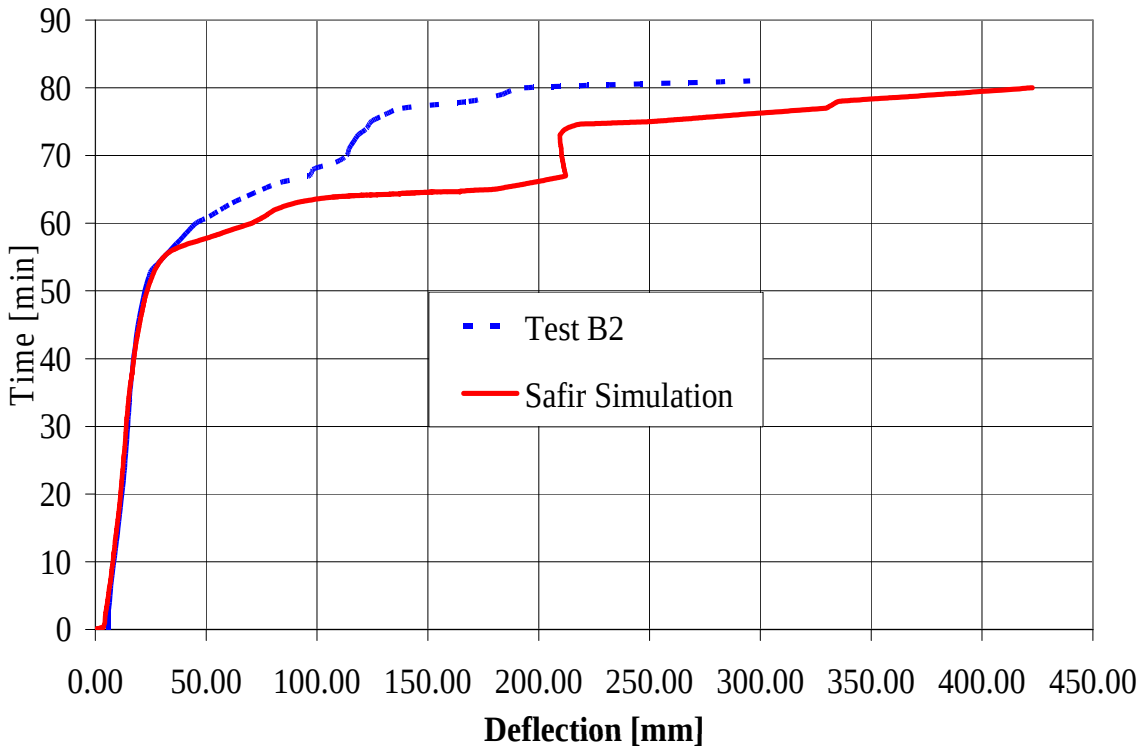


Cellular beam - Composite beam - Partial connection

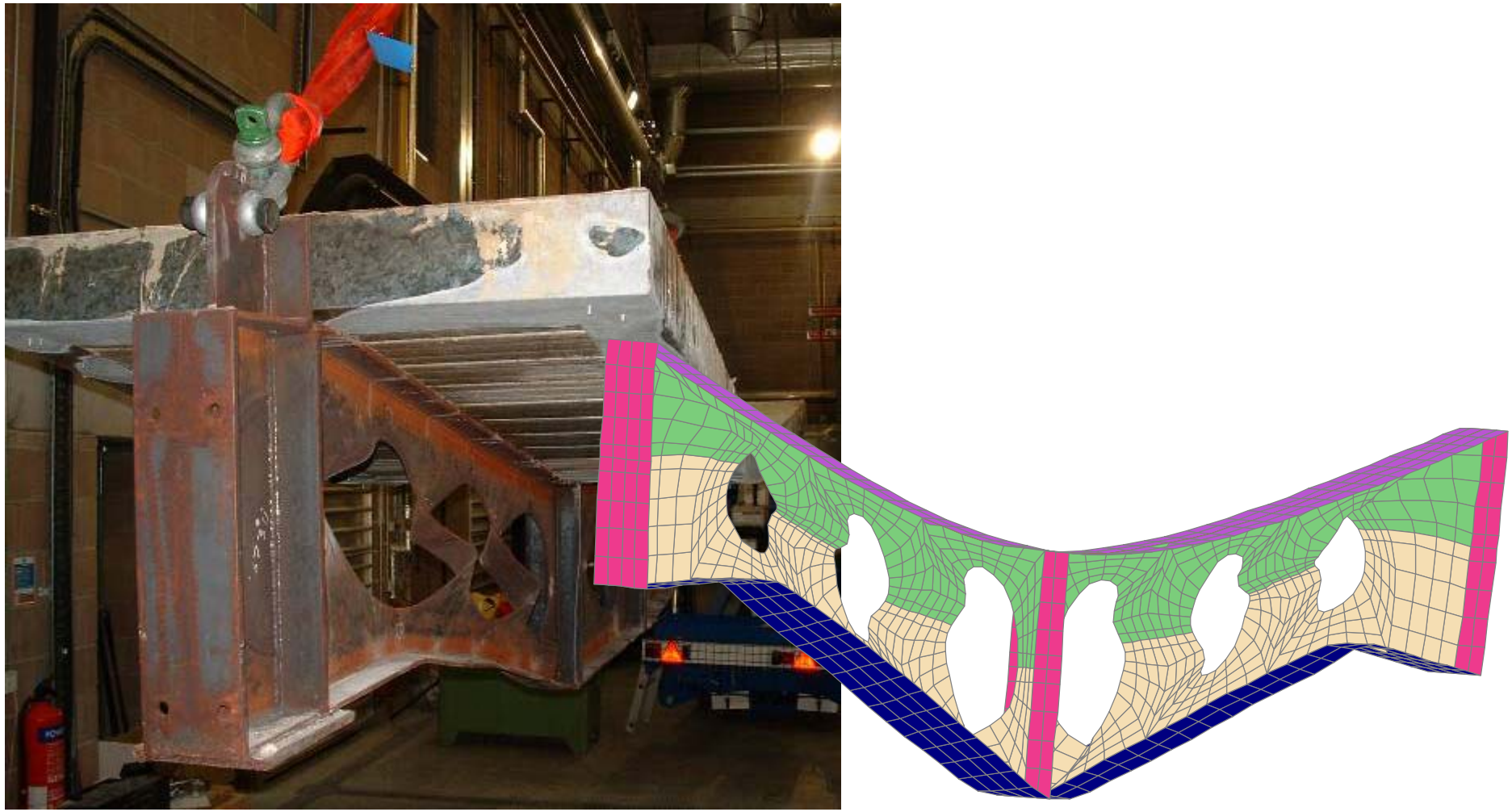


Cellular beam in case of fire : example

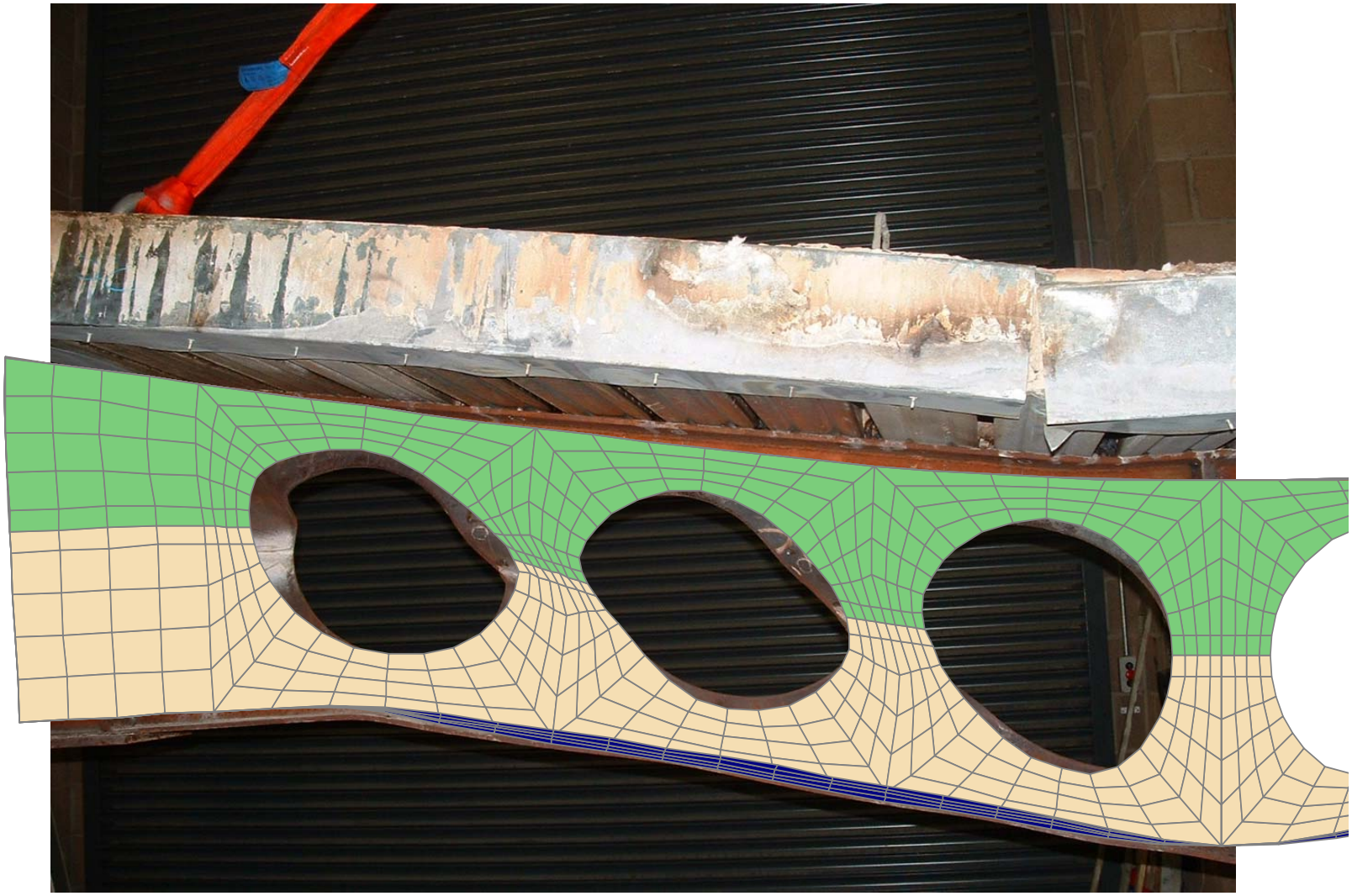




Cellular beam in case of fire : example

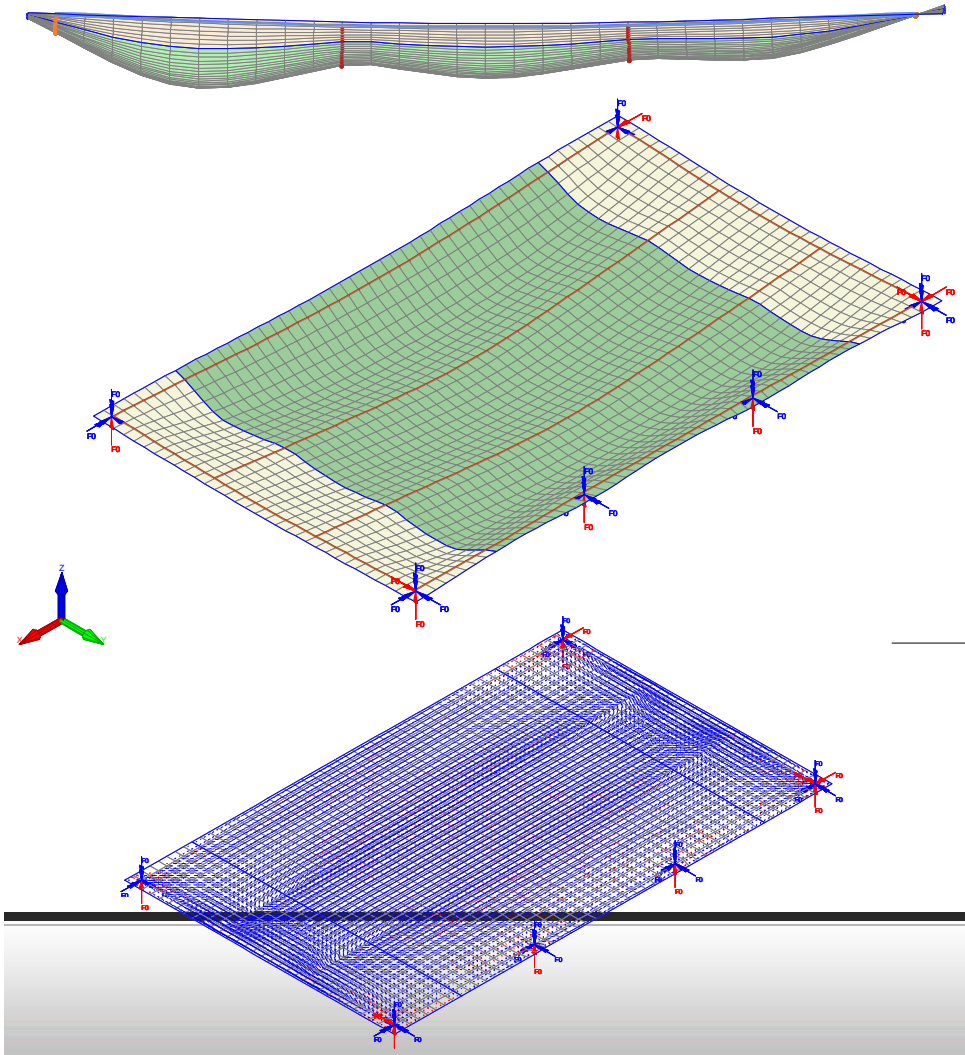


Cellular beam in case of fire : example

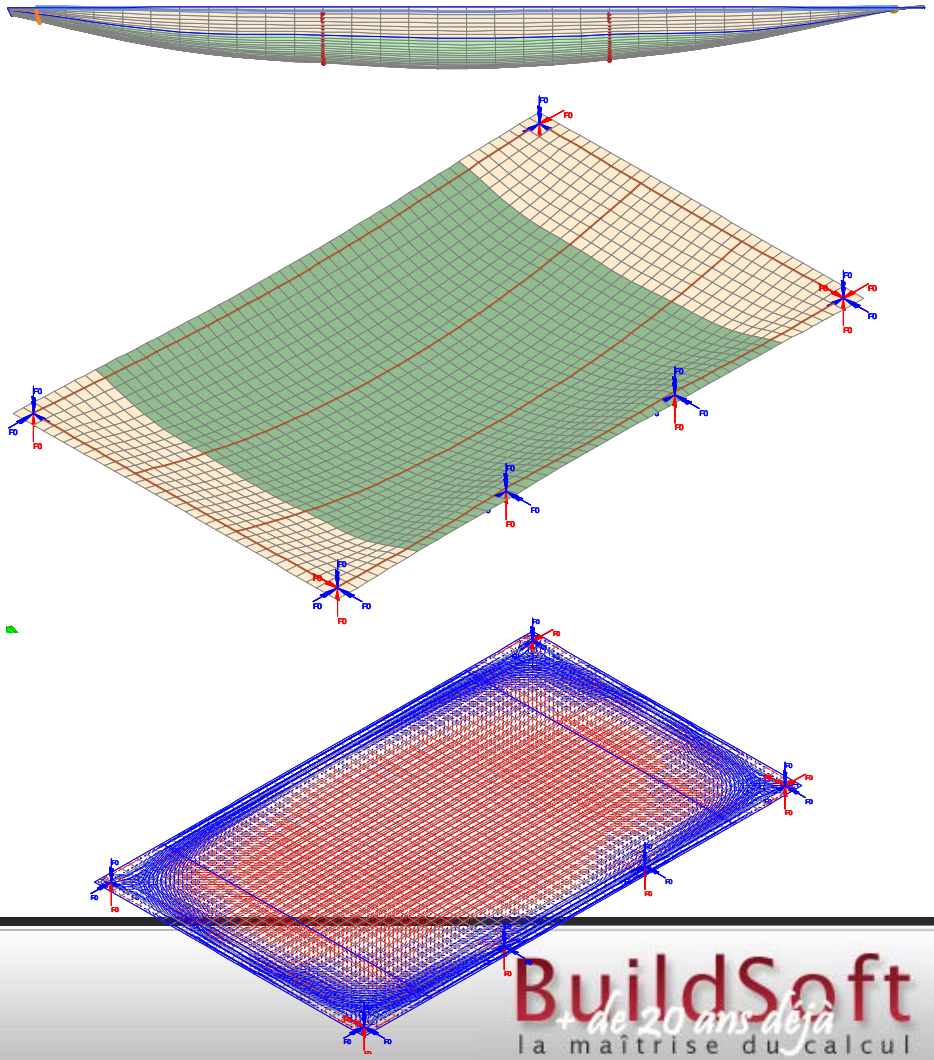


Tensile Membrane Action

Room temperature

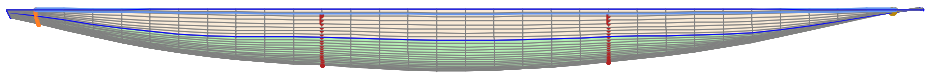


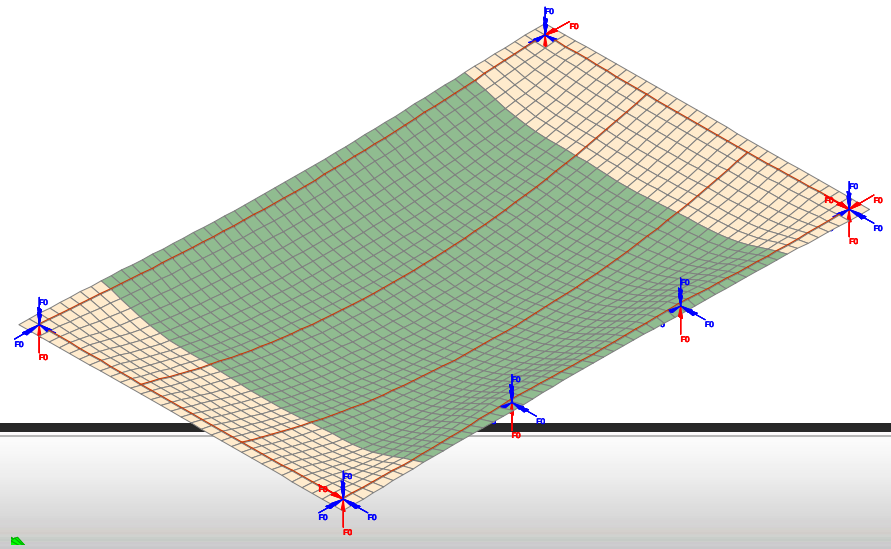
Fire Situation

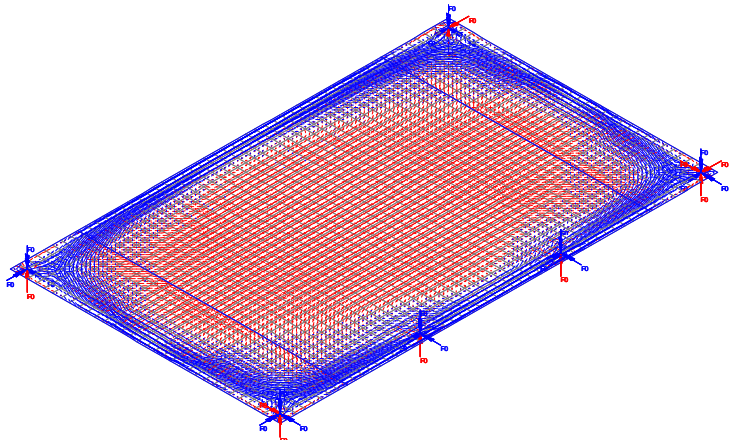


How is the load supported?

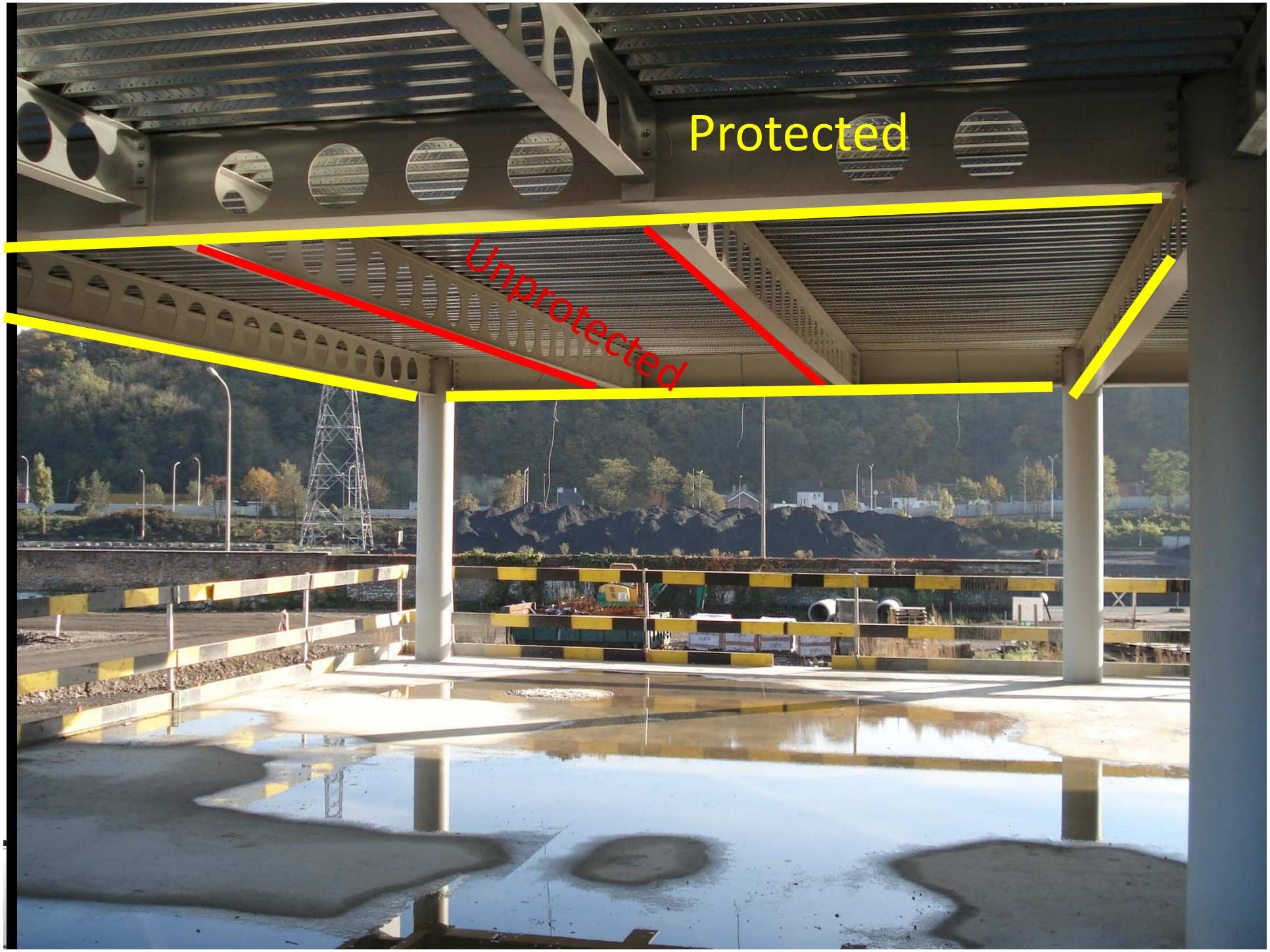
- The unprotected central steel beams loose all strength and stiffness.
- The slab behaves as a membrane.
- High deflections are reached in order to equilibrate vertical loads.
- The slab is highly cracked and the steel mesh is in tension.
- The tension in the central part is equilibrated by a compression ring within the slab.








Example: administrative building
of ArcelorMittal in Flémalle


Protected
Unprotected

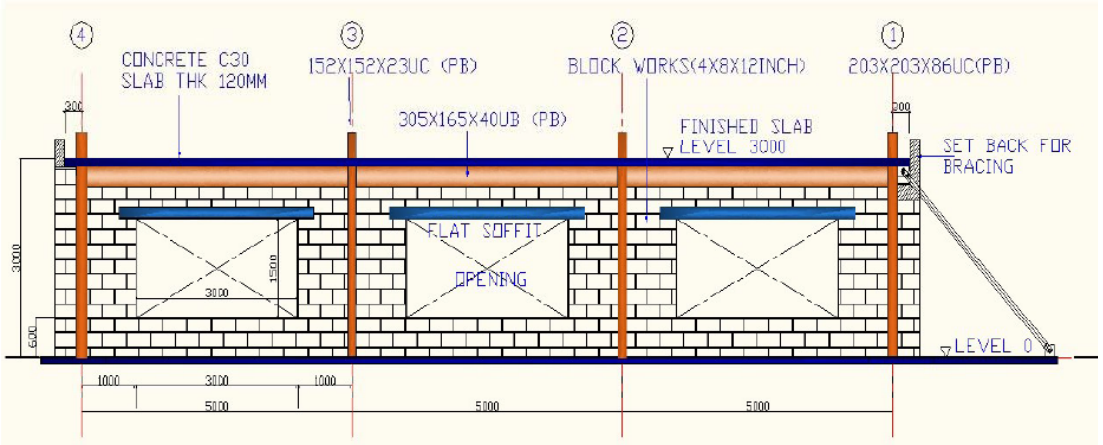
A full scale test, somewhere in Europe

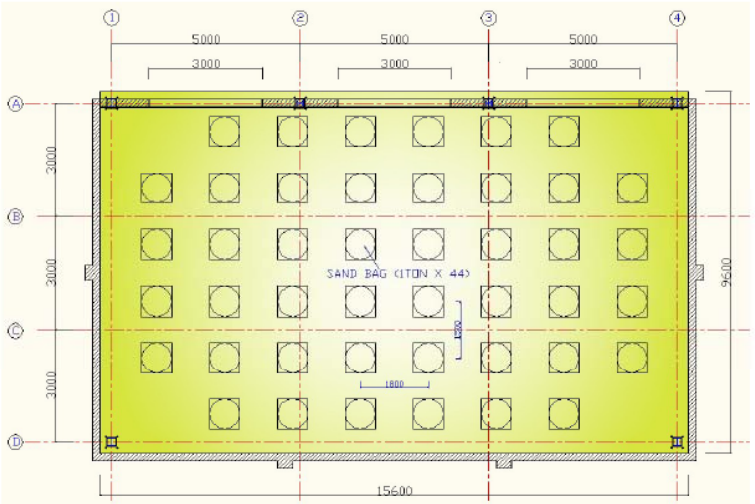
Result ?

So what ?

Full scale fire test (Ulster)
RFCS research « FICEB »

- Natural fire in a compartment of 9m by 15m
- Composite slab supported by two central unprotected beams
- Peripheral protected beams





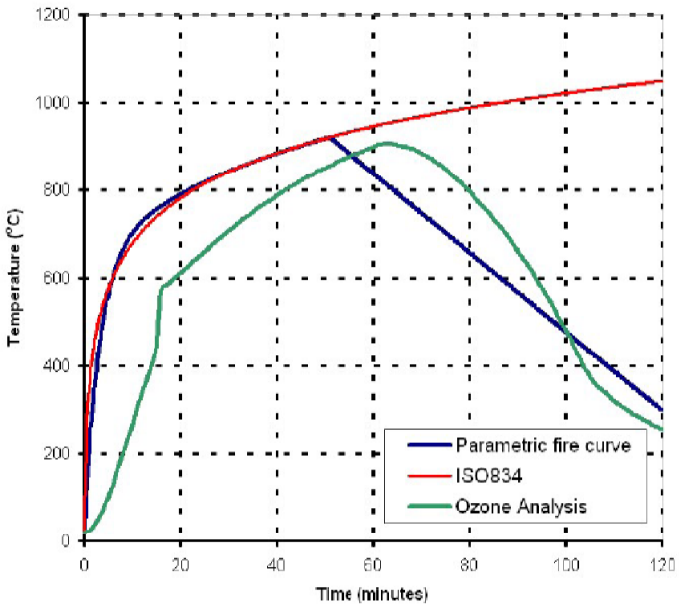
Fire development

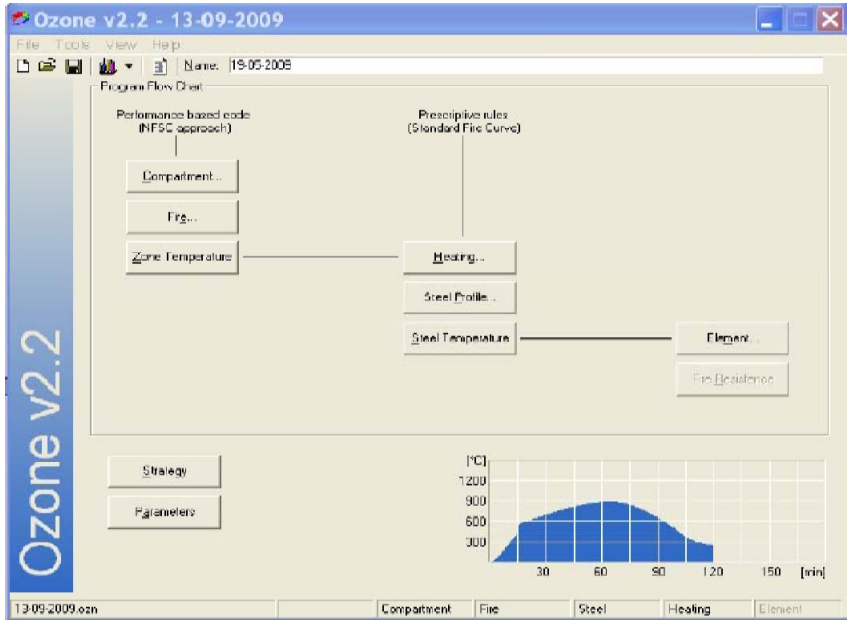
First step: to model the fire that will develop in the compartment (Ozone)

Fire load by 45 standard wooden crips (33 kg/m²)

Fire development

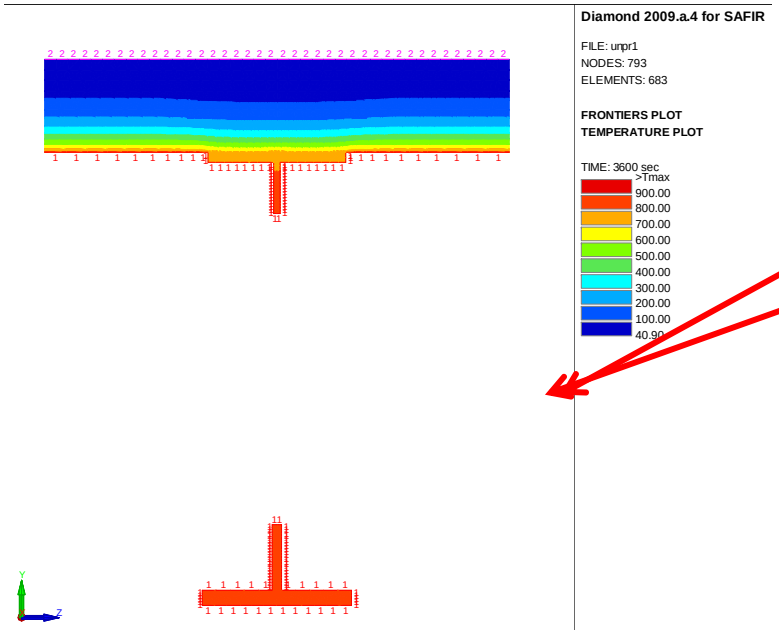
OZone software

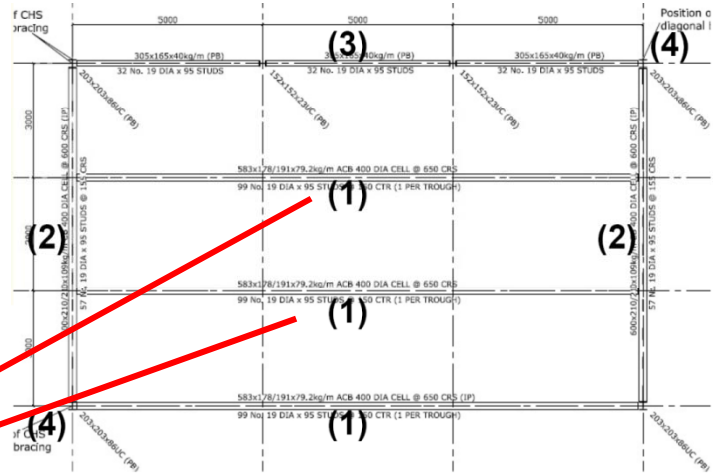




This calculation gives the gas temperature as a function of time in the compartment.

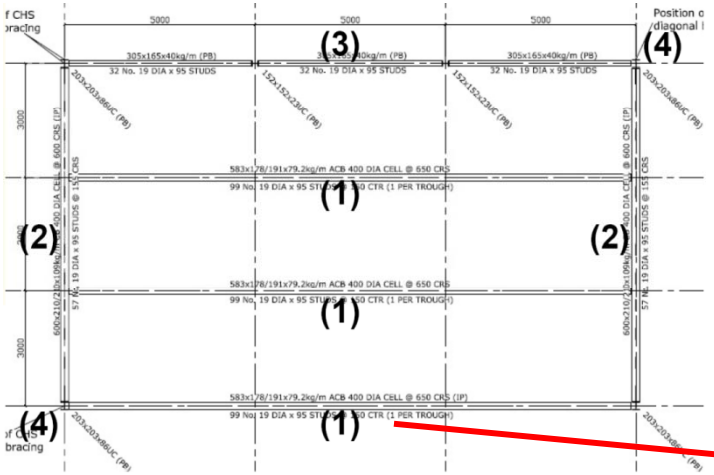
Thermal analysis of the beams

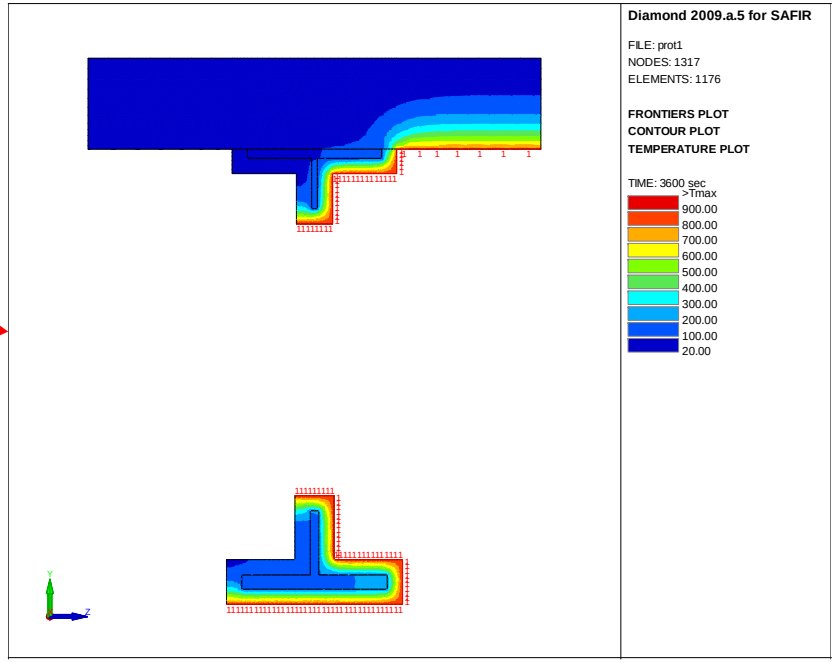




Central beams (1) are unprotected

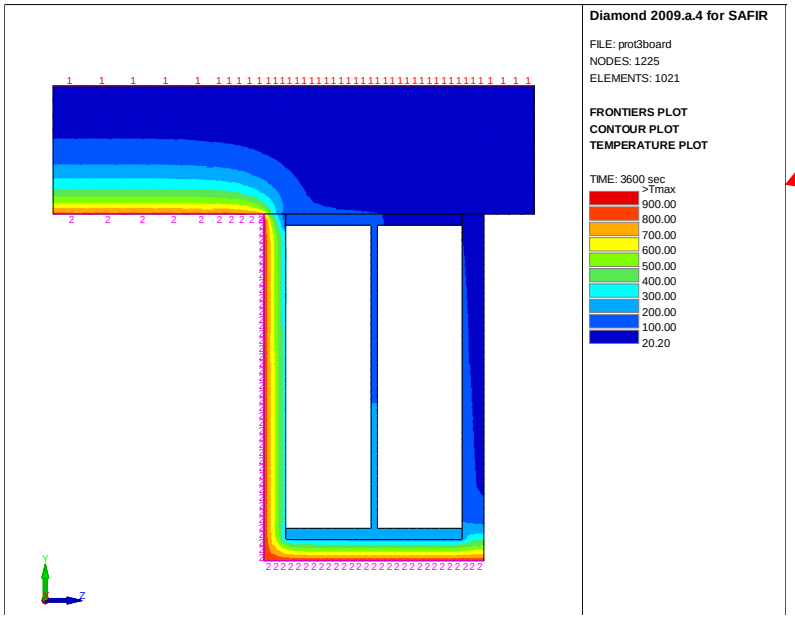
Thermal analysis of the beams

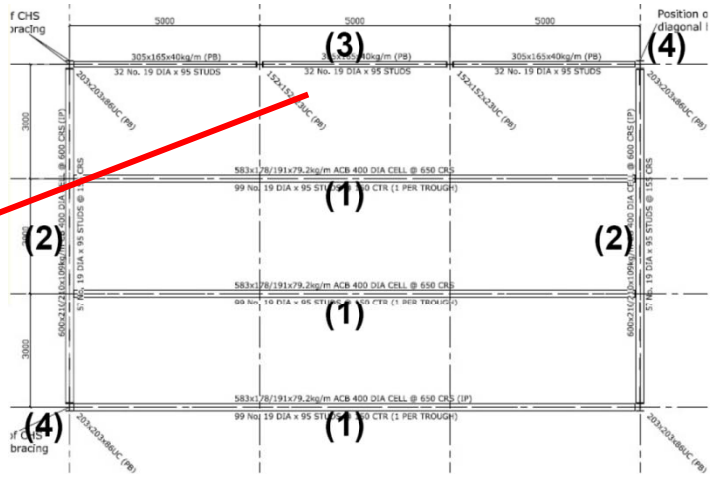




- Edge beam (1) is protected
- Attacked by the fire only on one side

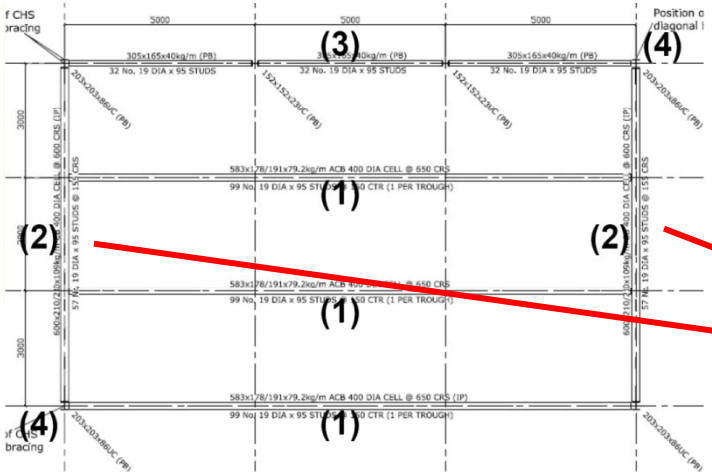
Thermal analysis of the beams

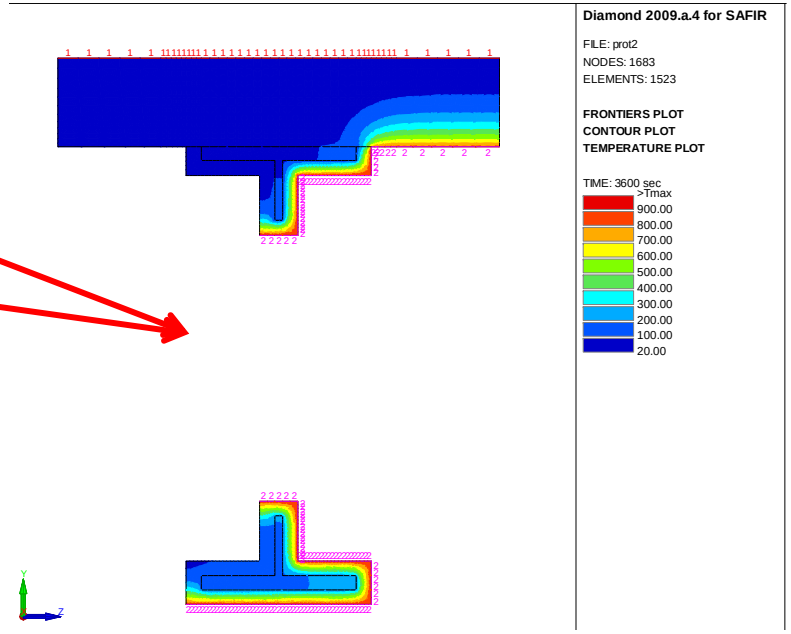




- Edge beam (3) is protected
- Attacked on one side

Thermal analysis of the beams

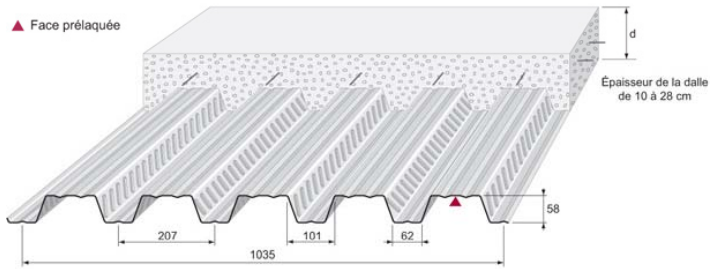


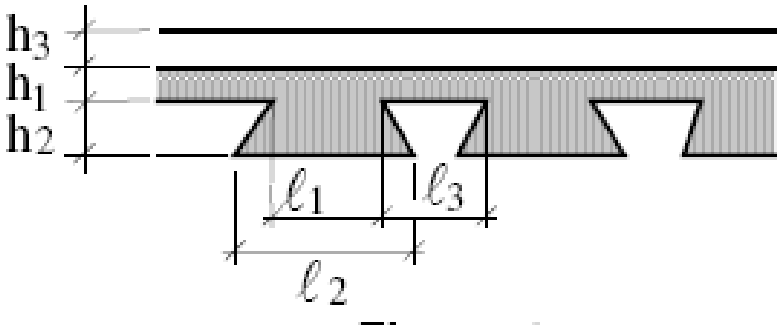


- Beams (2) are protected
- Attacked on one side

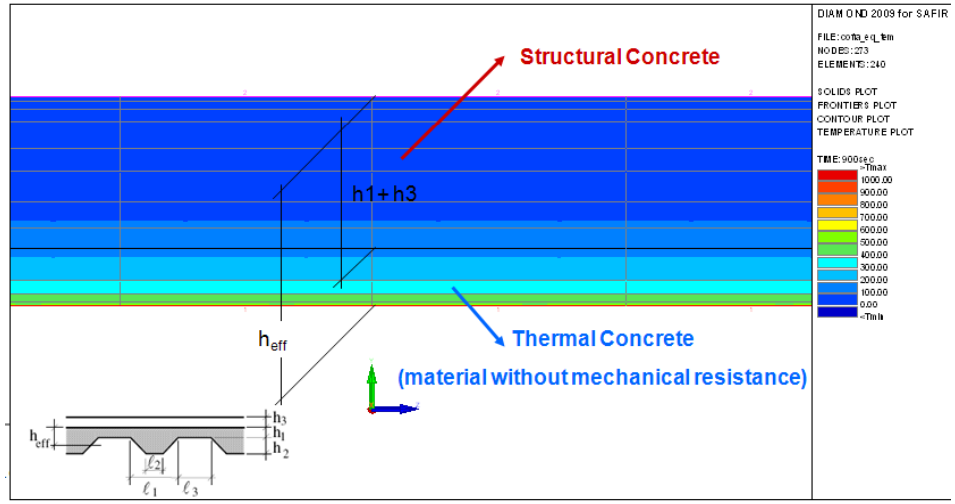
Thermal analysis of the slab

- Composite slab with steel deck
- The steel deck is not modeled and the geometry of the slab is simplified





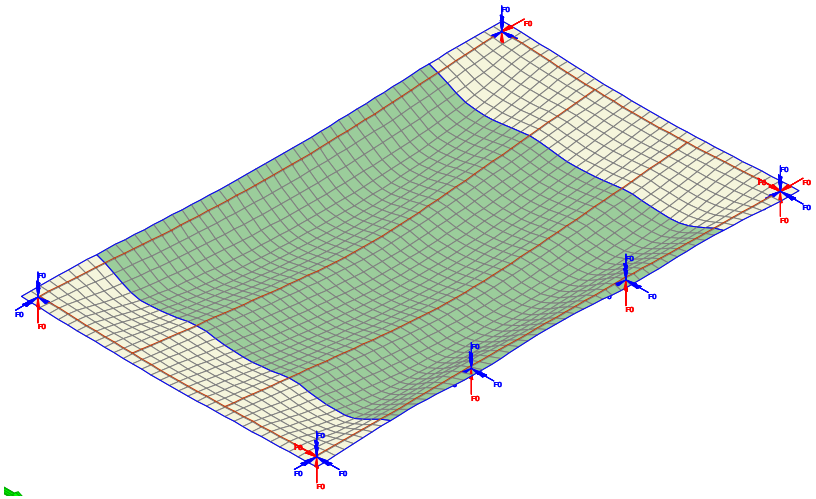
Thermal analysis of the slab



- The concrete in the ribs is partially considered for thermal analysis because it absorbs part of the heat (thermal analysis => effective thickness)
- Only the cover part of the slab is considered for structural analysis (structural analysis => only the cover thickness)

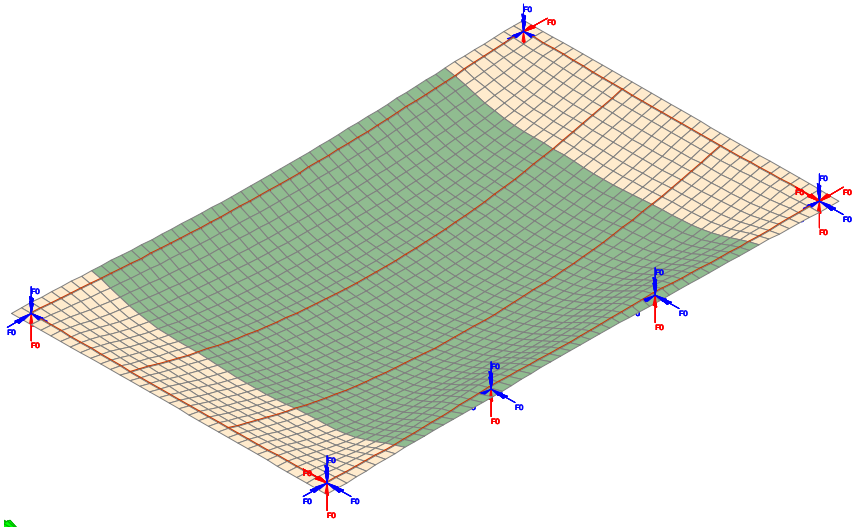
Structural analysis – room temperature

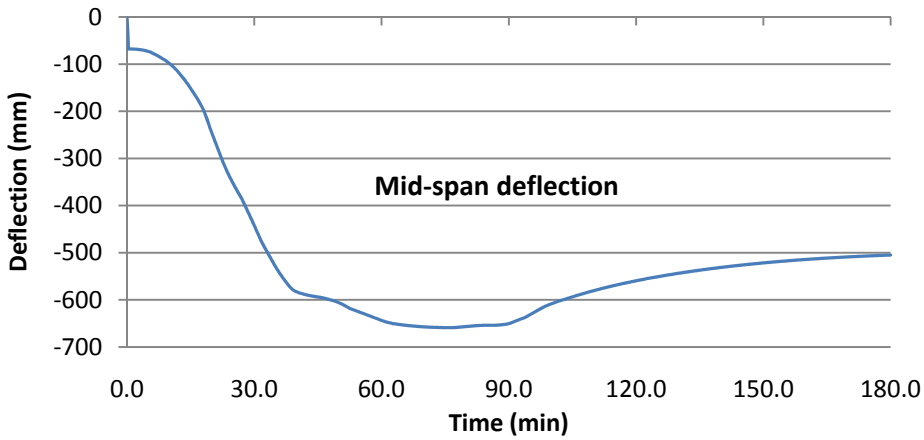
- Beam elements were used for the beams and shell elements for the slab
- The uniformly distributed load is increased until collapse.
- The structural behaviour is a bending mode



Structural analysis – fire situation

Structural behaviour totally different compared to the cold case: the unprotected beams lose their stiffness and the slab develops a tensile membrane action.






Authorised
Persons
ONLY
RESTRICTED
AREA
KEEP OUT


44 bags of 1 ton on the roof => 330 kg/m²

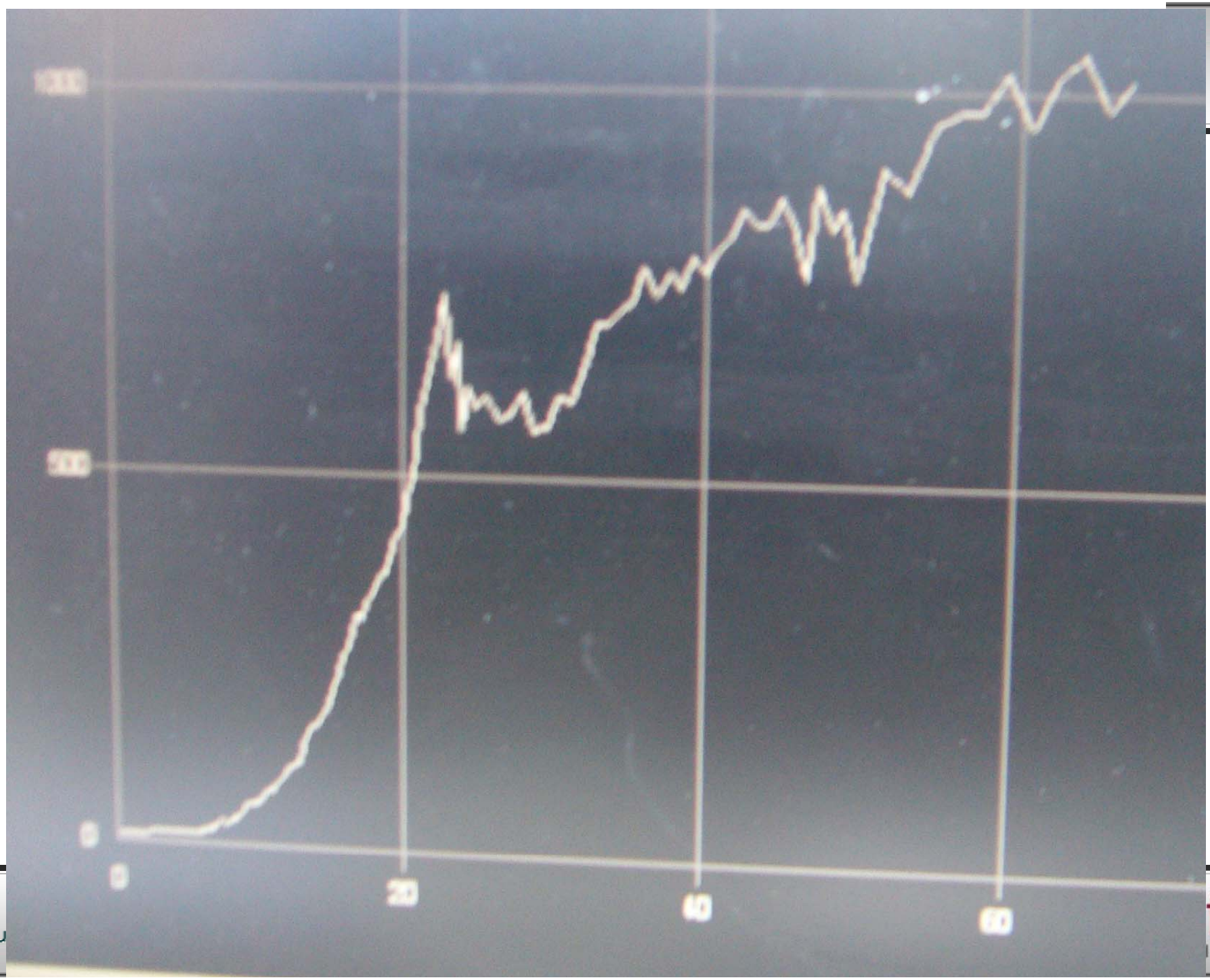

ZONE 4


00:31:24

VIDEO


00:42:47


00:56:07

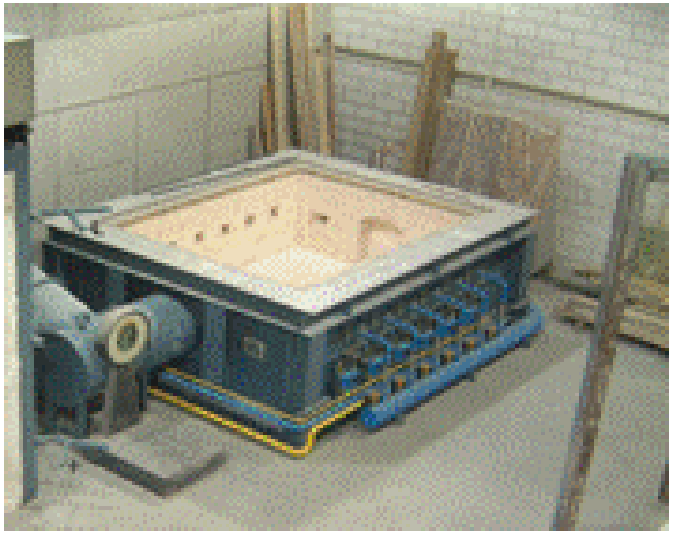

1000
500
0
0
20
40
60


01:28:28


DANGER
Construction Site
KEEP OUT

Facility : Fire Lab

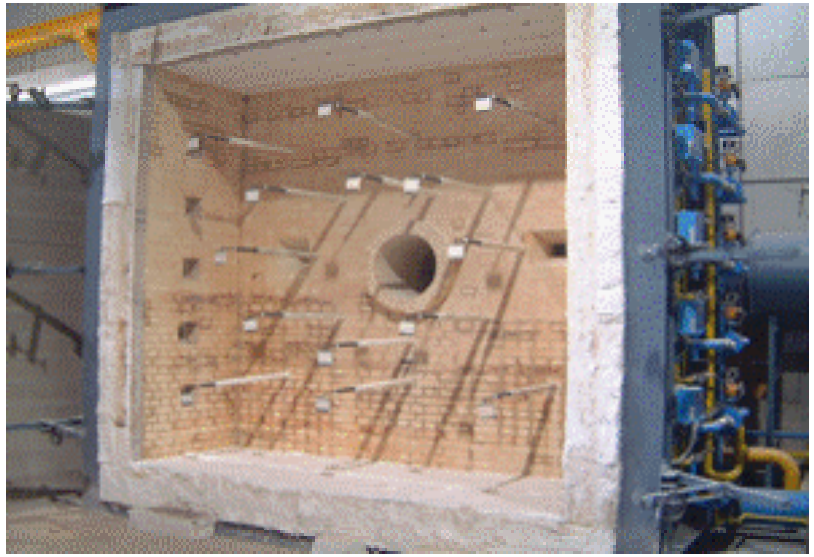
Horizontal furnace



- **Dimensions : 3 m x 4 m**
- **Max. load : 100 t**
- **Ceilings, slabs, floors, beams, roofings.**

Facility : Fire Lab

Vertical furnace



- **Dimensions : 3.25 m x 3.25 m**
- **Max. load : 300 t**
- **Dividing walls, structural walls, doors, façades, electric cables.**


Thank you.
© the white planes picture co.