SAFIR
A software for modelling the behaviour of structure subjected to the fire

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SAFIR

Introduction
Basic theory of thermal calculations

Three steps in the structural fire design:

1. *Define the fire (not made by SAFIR).*

2. *Calculate the temperatures in the structure.*

3. *Calculate the mechanical behaviour.*

Step 1

Define the fire (that will then be taken as a data by SAFIR)

Option 1: a design fire $T_g = f(t)$

- Either
  - ISO 834,
  - hydrocarbon curve of Eurocode 1,
  - external fire curve of Eurocode 1,
  - ASTM E119,

    all embedded in SAFIR
- or choose your own time-temperature curve (from zone modelling for example) and describe it point by point in a text file.

Heat flux linked to a T_g-t curve:

$$\dot{q} = h\left(T_g - T_S\right) + \sigma\varepsilon\left(T_g^4 - T_S^4\right)$$

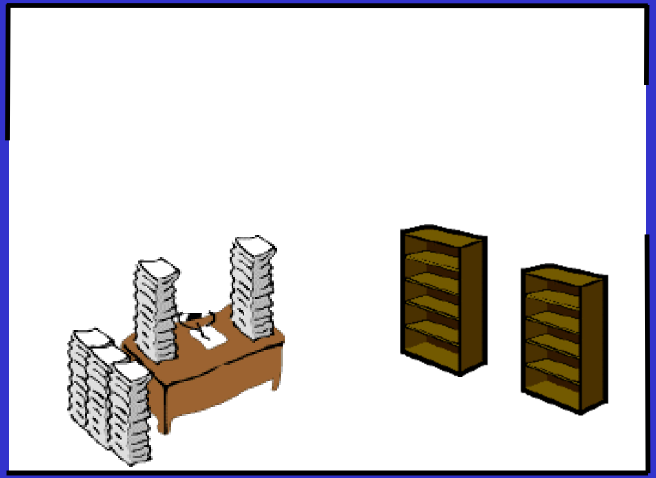
Example of a tool for determining Temperature-time curve:

OZone V2.0.XX

OZone V2.0.XX

Fire phases and associated model

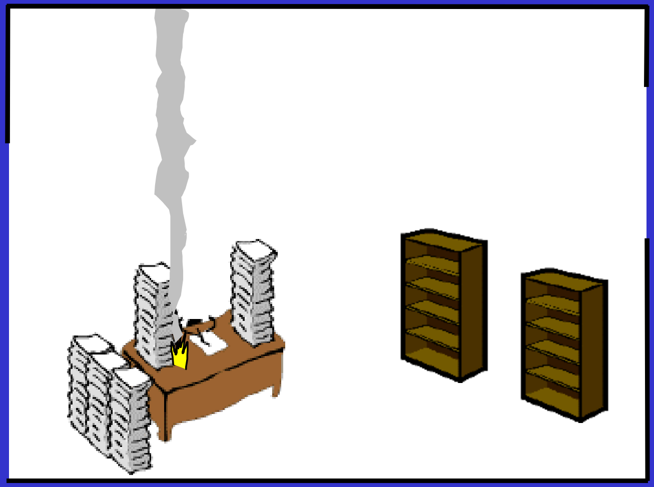
The compartment.



OZone V2.0.XX

Fire phases and associated model

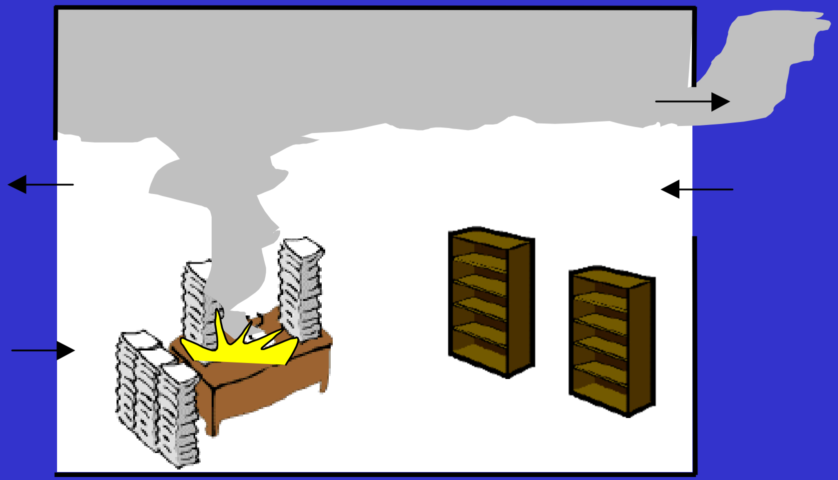
The fire starts.



OZone V2.0.XX

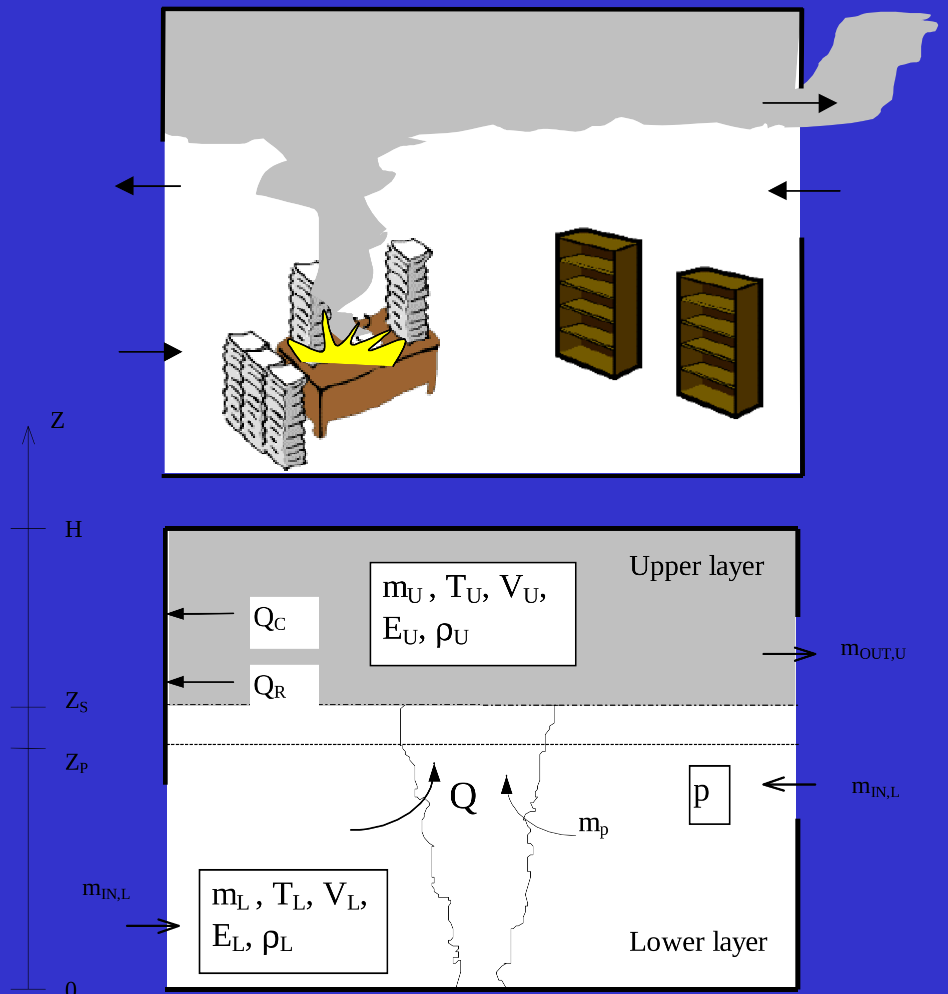
Fire phases and associated model

Stratification in 2 zones.



OZone V2.0.XX

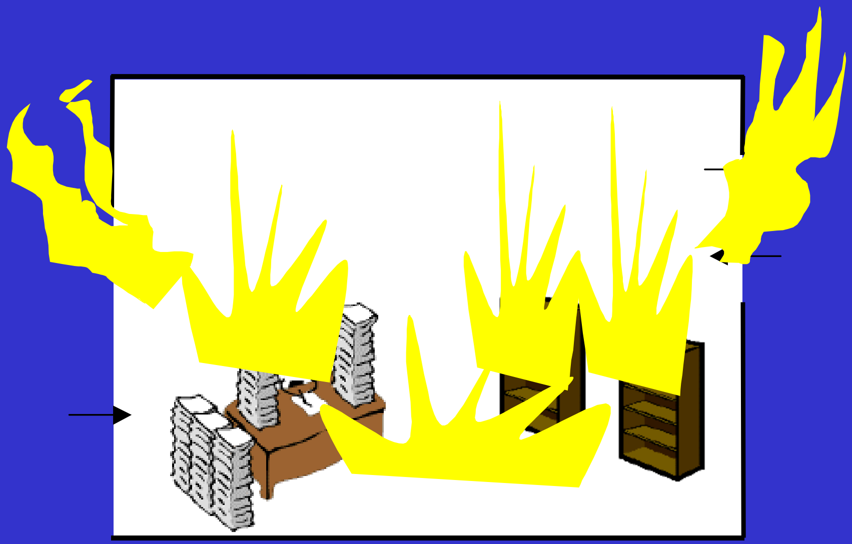
Fire phases and associated model
2 zones model.



OZone V2.0.XX

Fire phases and associated model

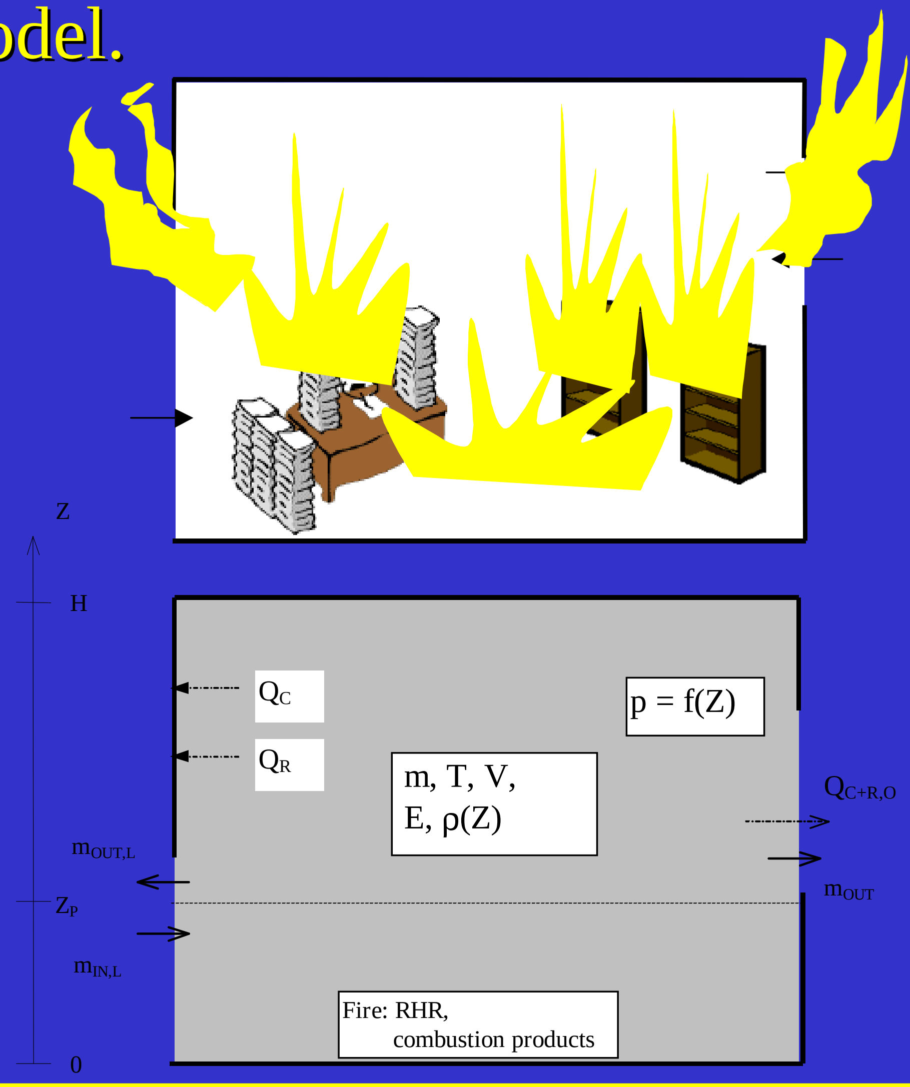
Flash over.



OZone V2.0.XX

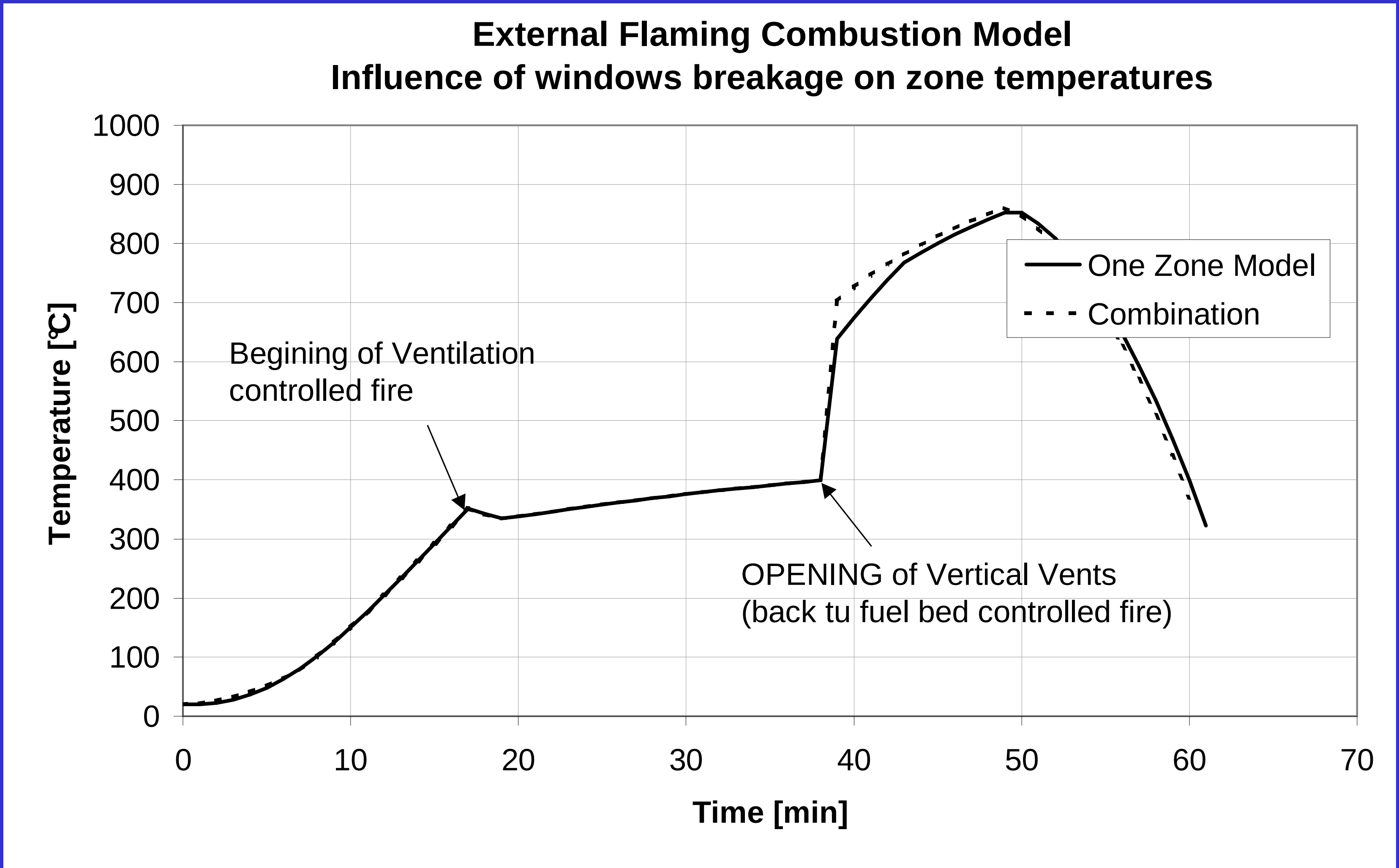
Fire phases and associated model

1 zone model.



OZone V2.0.XX

Result to be used by SAFIR : the time-temperature curve



Option 2: a flux at the boundary

$$q^{\bullet} = f(t)$$

f(t) is described point by point in a text file

Option 3: a flux defined by the local fire model of EN 1991-1-2 (Hasemi's model).

See advanced SAFIR course.

Steps 2 & 3

Thermal & mechanical calculations

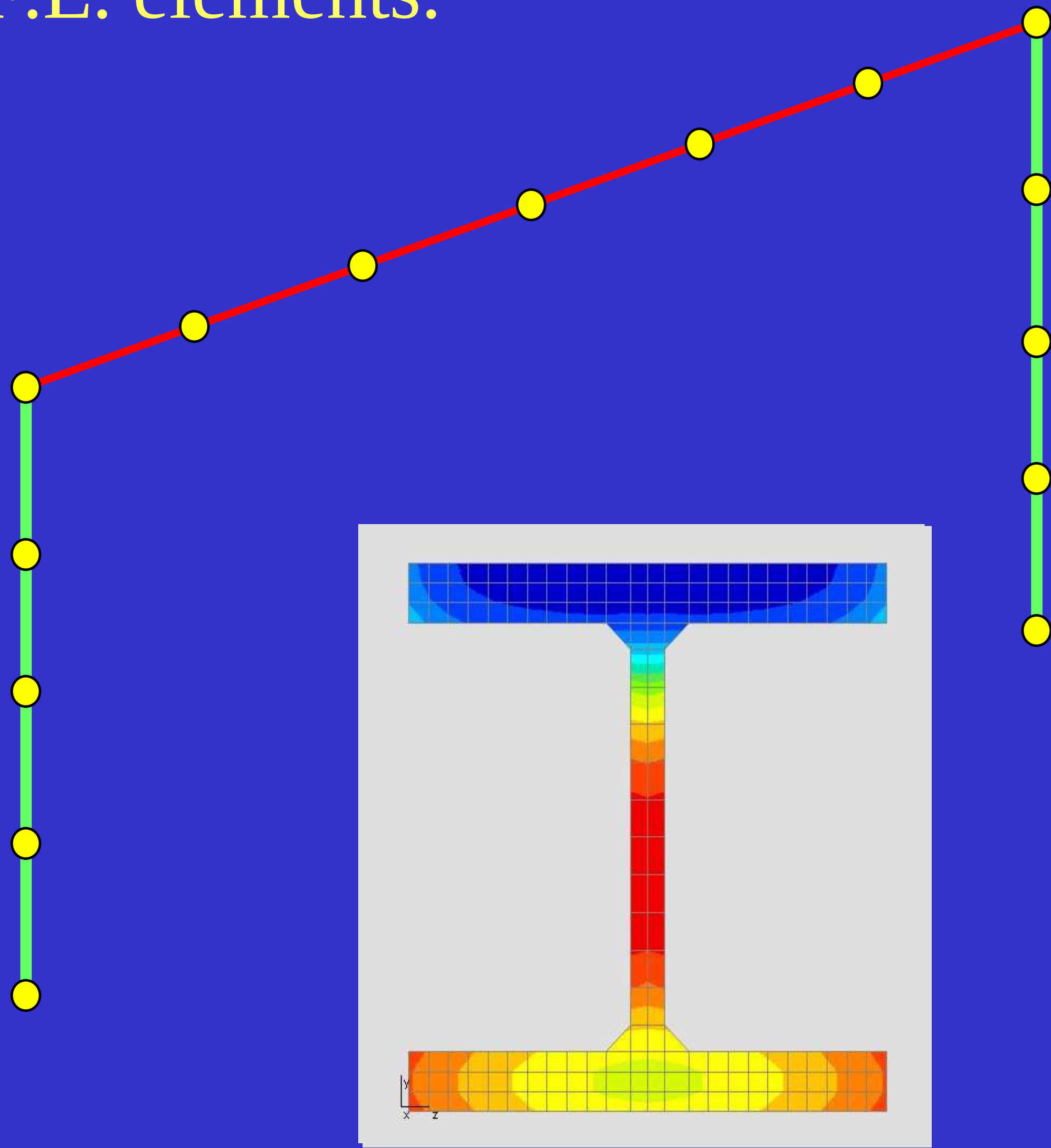
Link between thermal and mechanical analyses

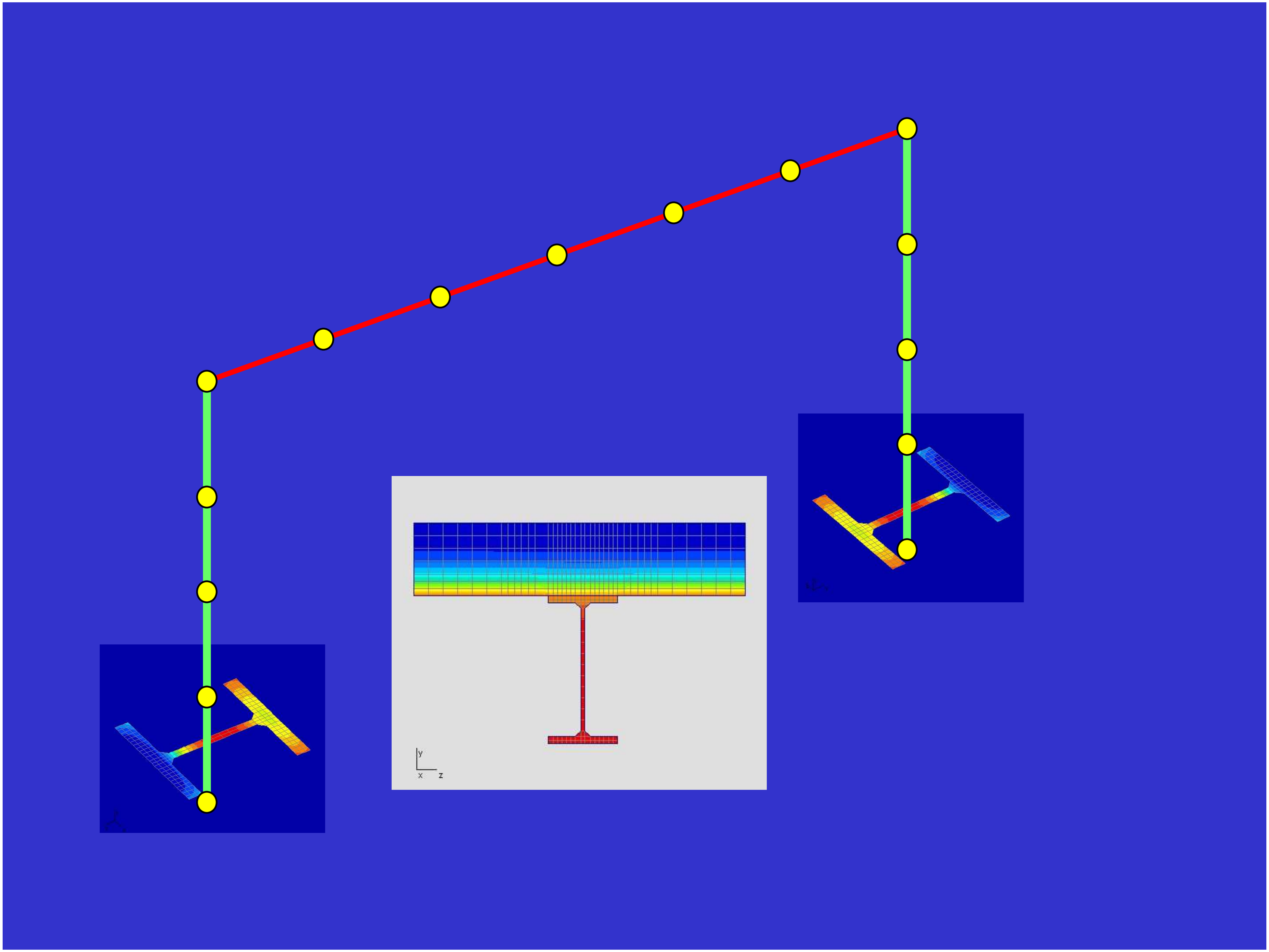
The type of model used for the thermal analysis depends on the type of model that will be used in the subsequent mechanical analysis.

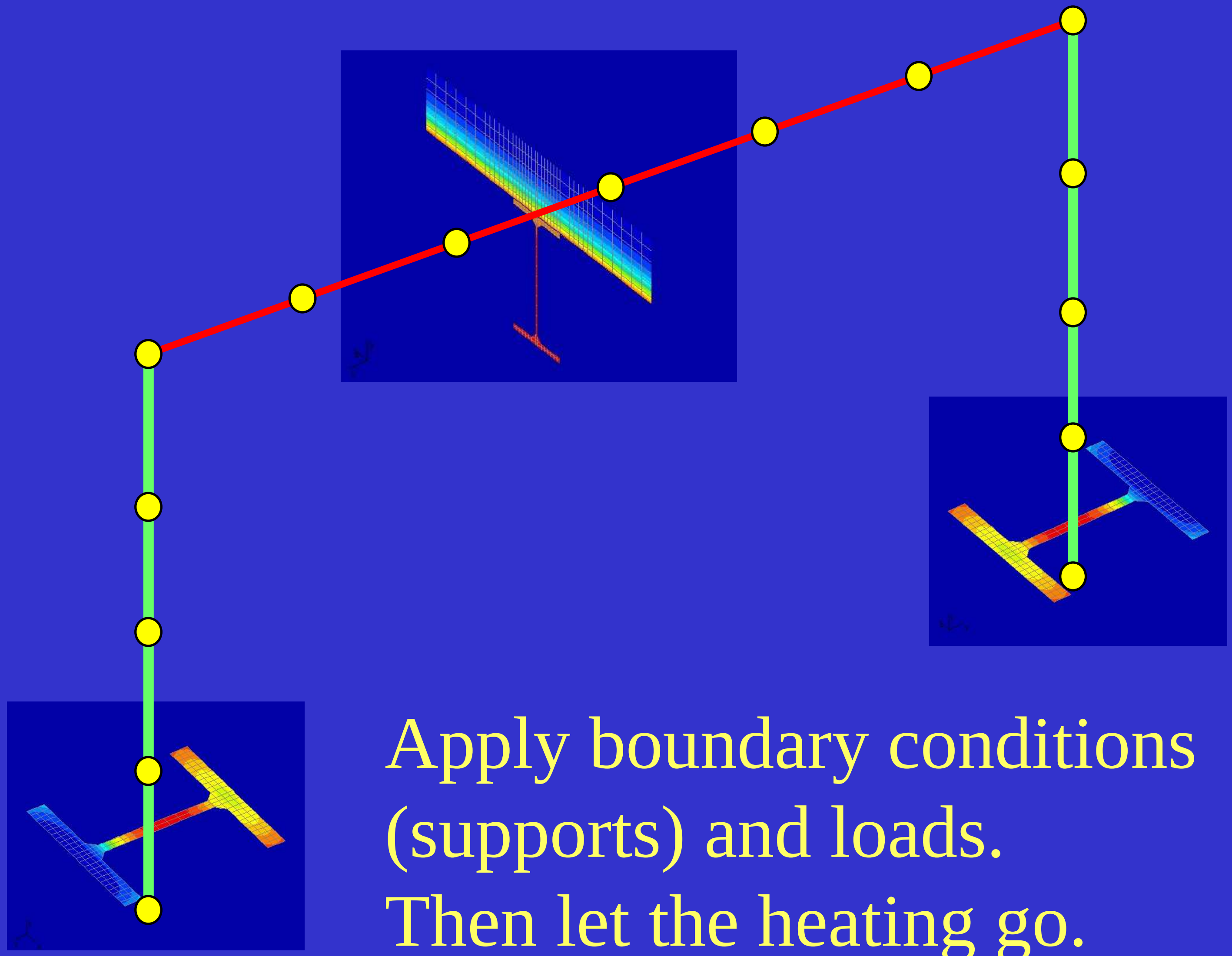
Link between thermal and mechanical analyses

	Temperature field		Mechanical model
	3D F.E.	=>	Simple calculation model
Today	**2D F.E.**	=>	**Beam F.E. (2D or 3D)**
	1D F.E. or user's field	=>	Shell F.E. (3D)
	Simple calculation model	=>	Truss F.E. (2D or 3D)

General principle of a mechanical analysis based on beam F.E. elements.




y
x
z

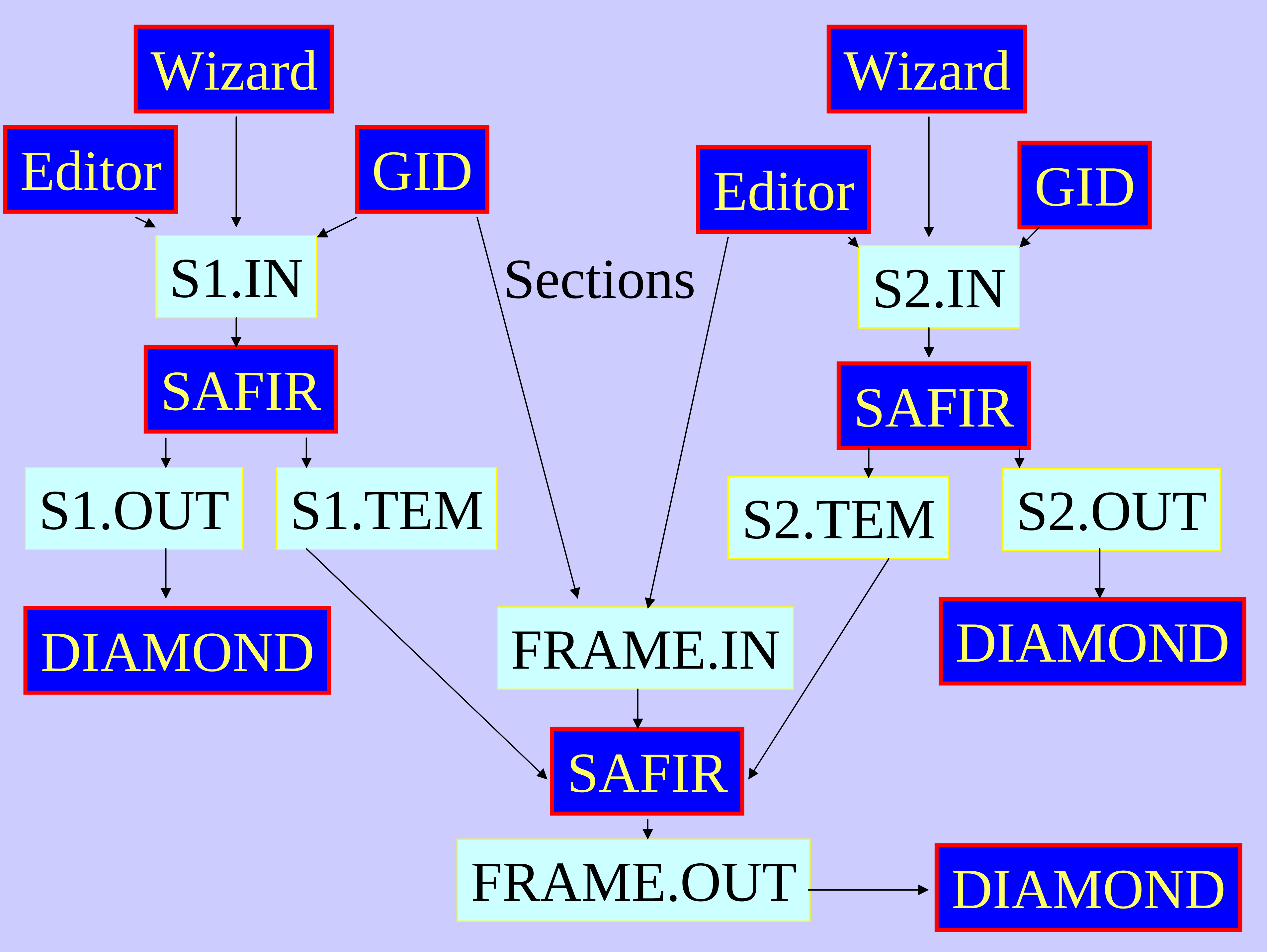


Apply boundary conditions (supports) and loads.
Then let the heating go.

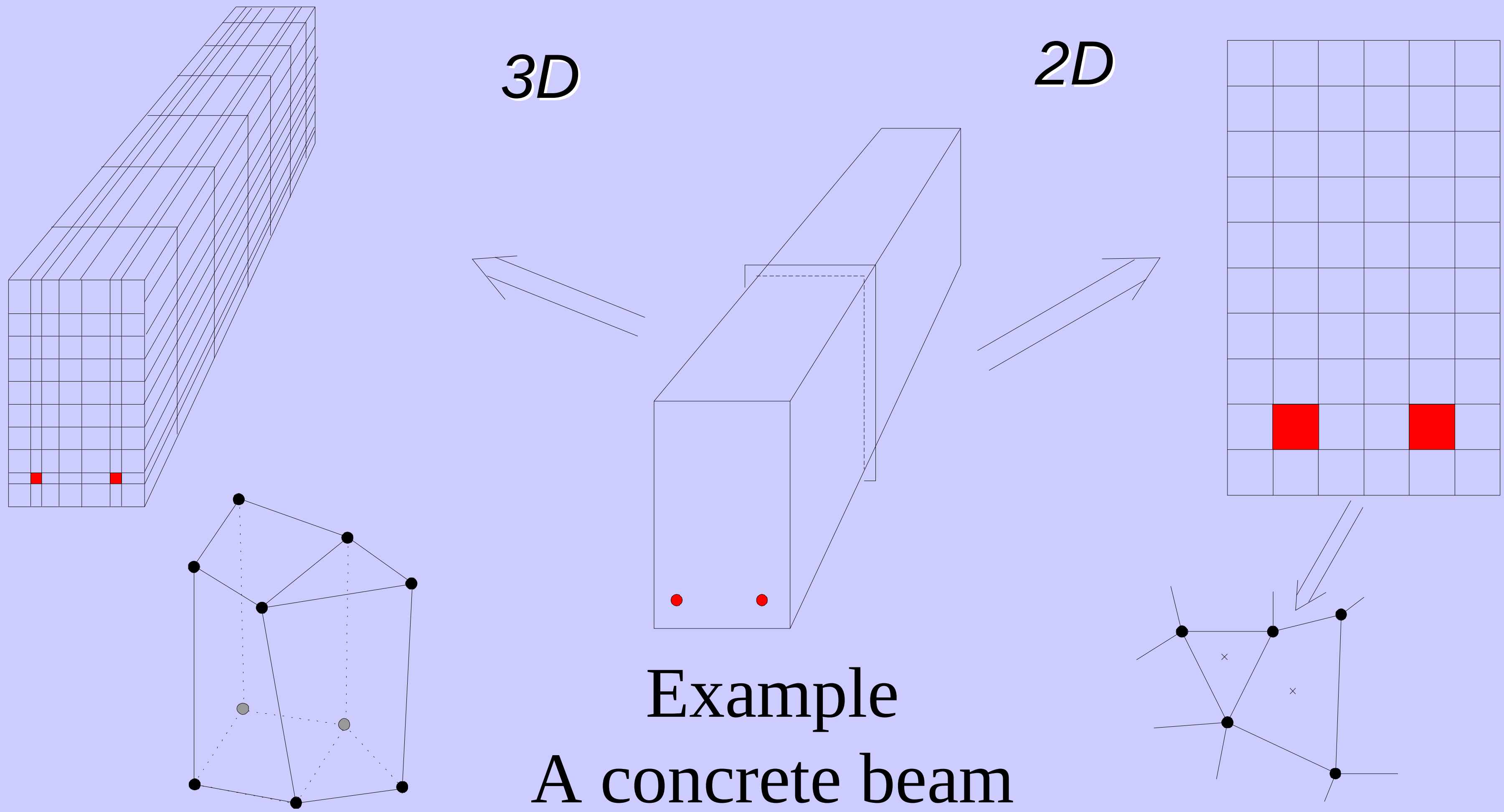
Organisation of the files for a typical calculation (one mechanical calculation for a structure with 2 section types)

Note: one new section type if:

- the geometry of the section is different,
- the fire curve is different,
- the thermal properties are different,
- the mechanical properties are different.

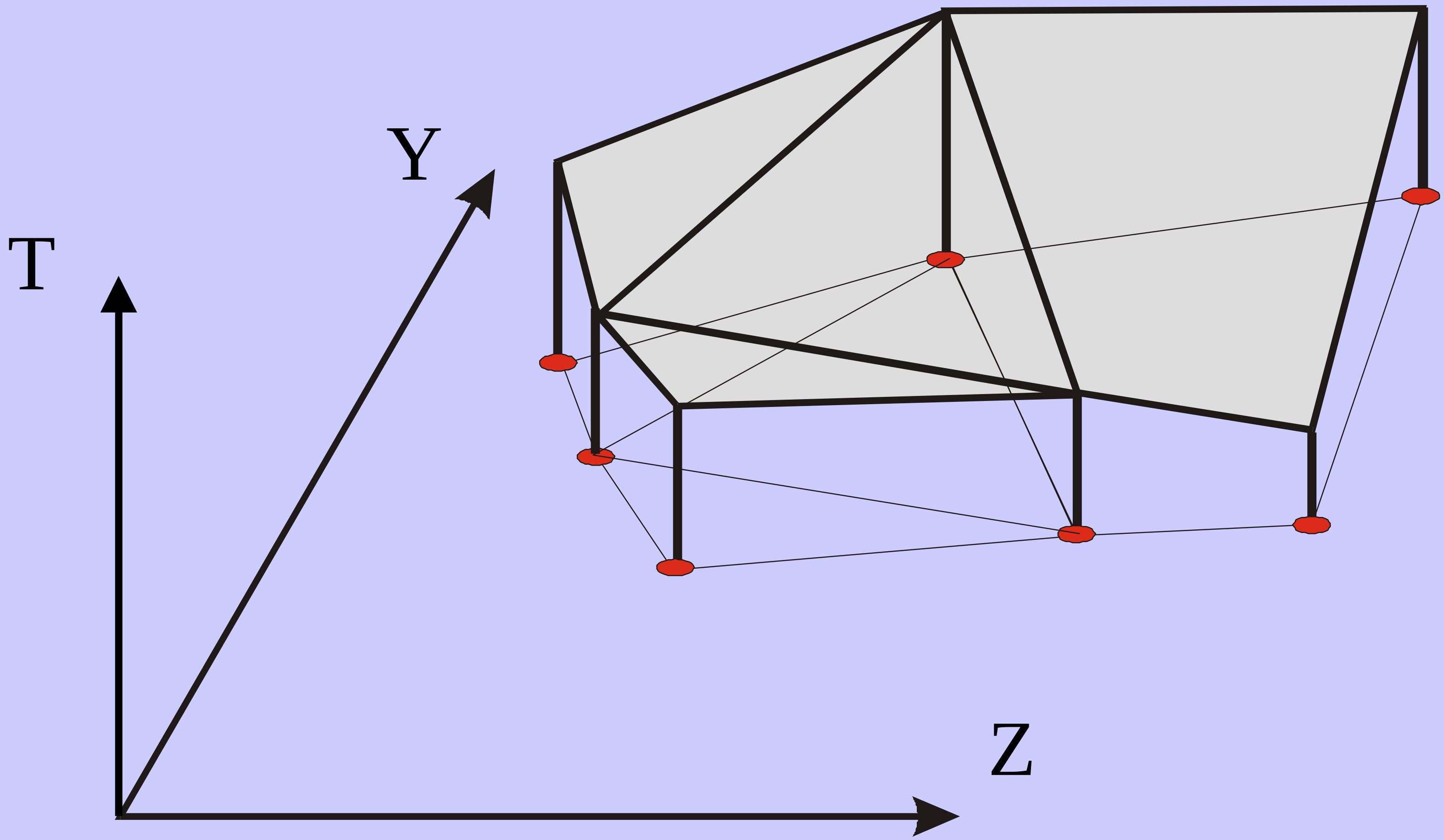

Wizard
Editor
GID
S1.IN
SAFIR
S1.OUT
S1.TEM
DIAMOND
Sections
Wizard
Editor
GID
S2.IN
SAFIR
S2.TEM
S2.OUT
DIAMOND
FRAME.IN
SAFIR
FRAME.OUT
DIAMOND

Step 2. Thermal Calculation - discretisation of the structure

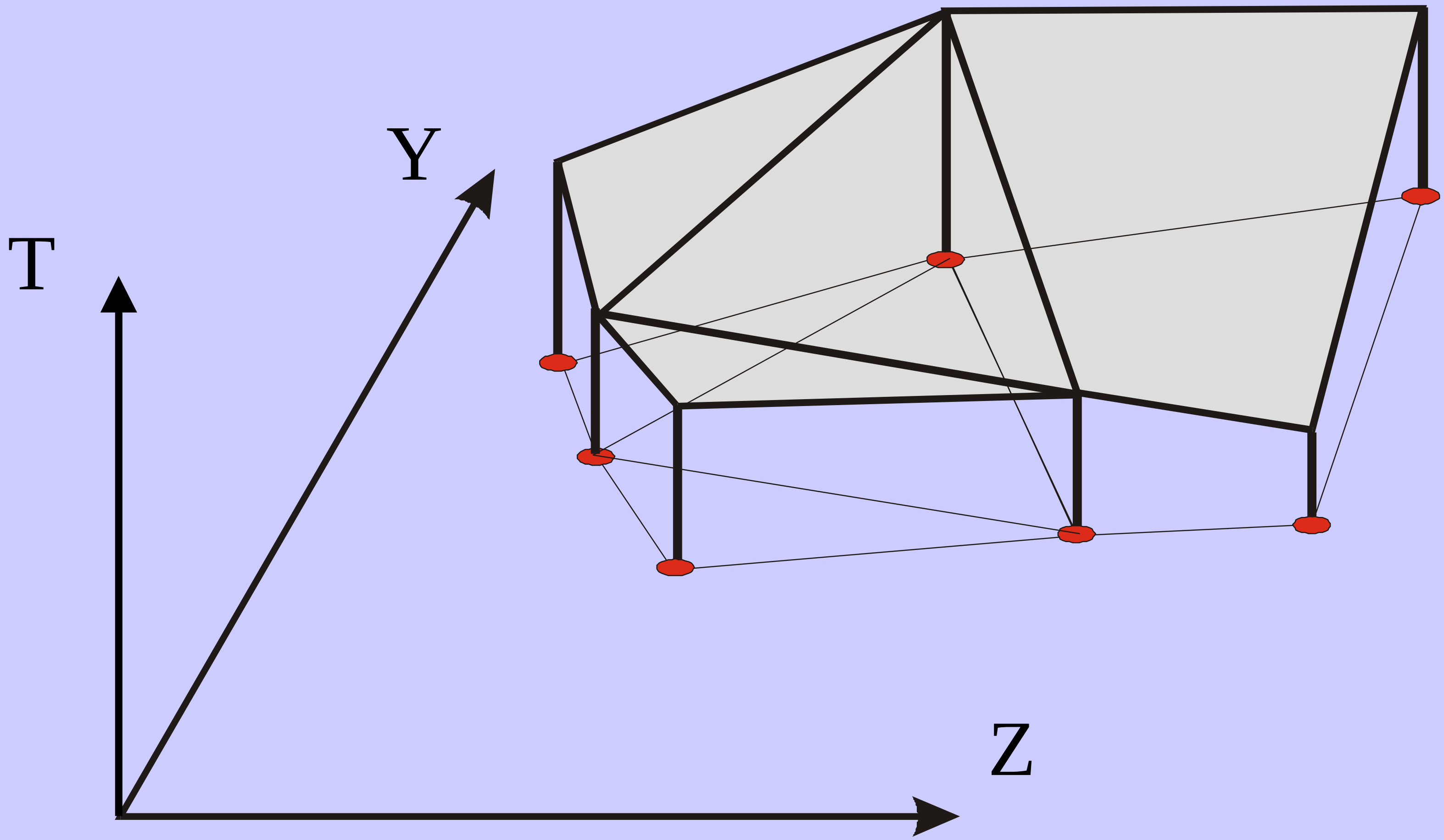


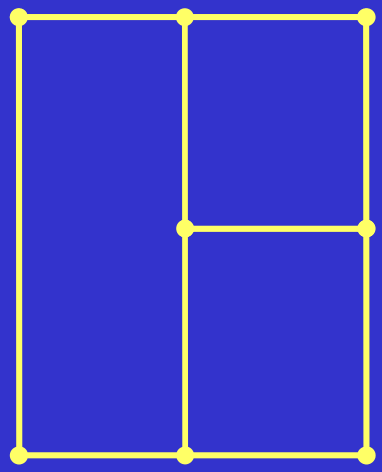
Example
A concrete beam

2D thermal model – meshing of the section with 3 or 4 noded linear elements (the temperature is represented by the vertical elevation).

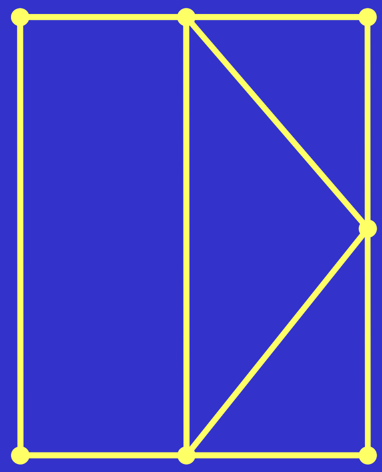


The temperature varies linearly along the edges of the elements => C_0 continuity for the temperature field



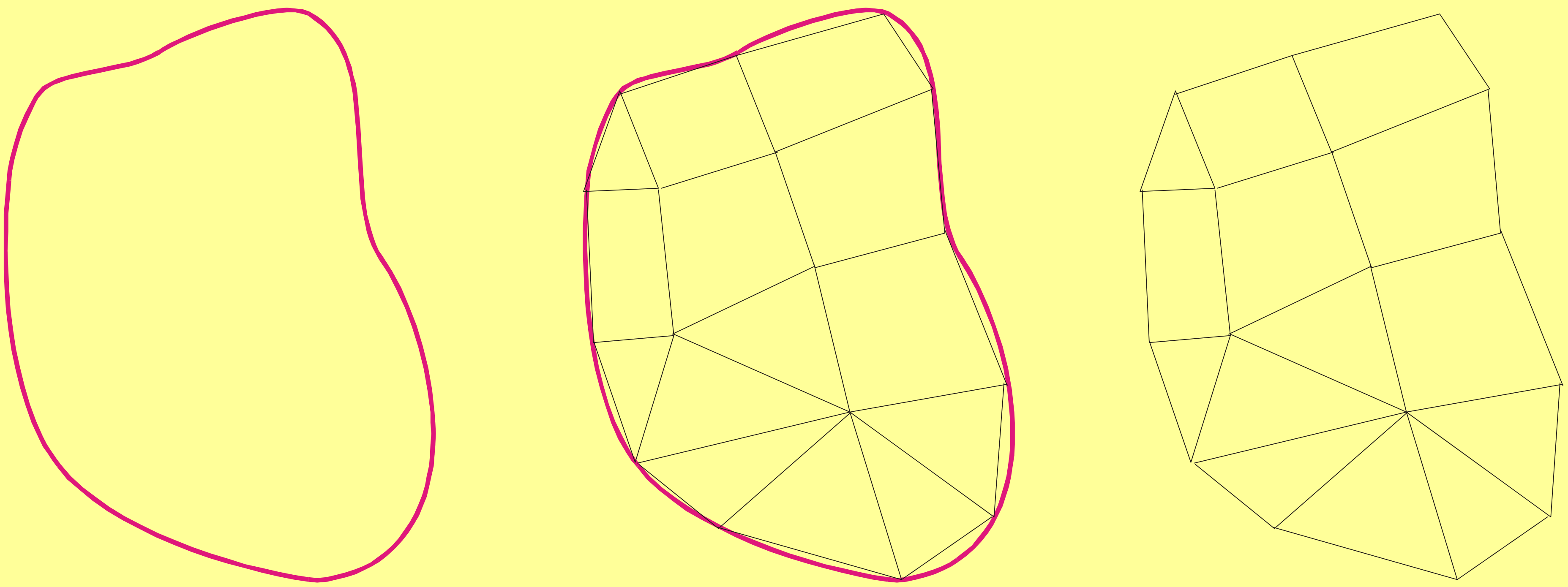


Not correct



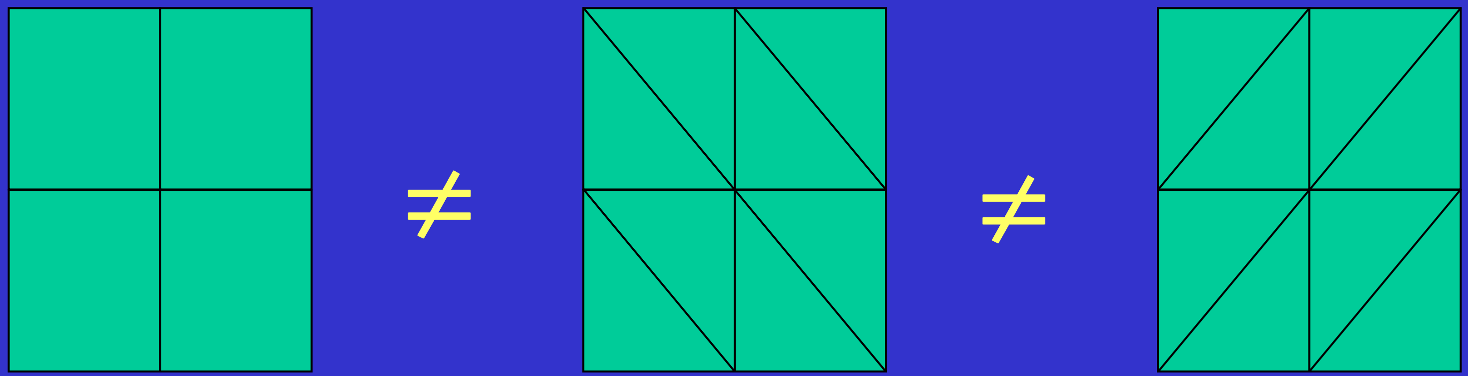
Correct

Step 2. Thermal response : discretisation of the structure



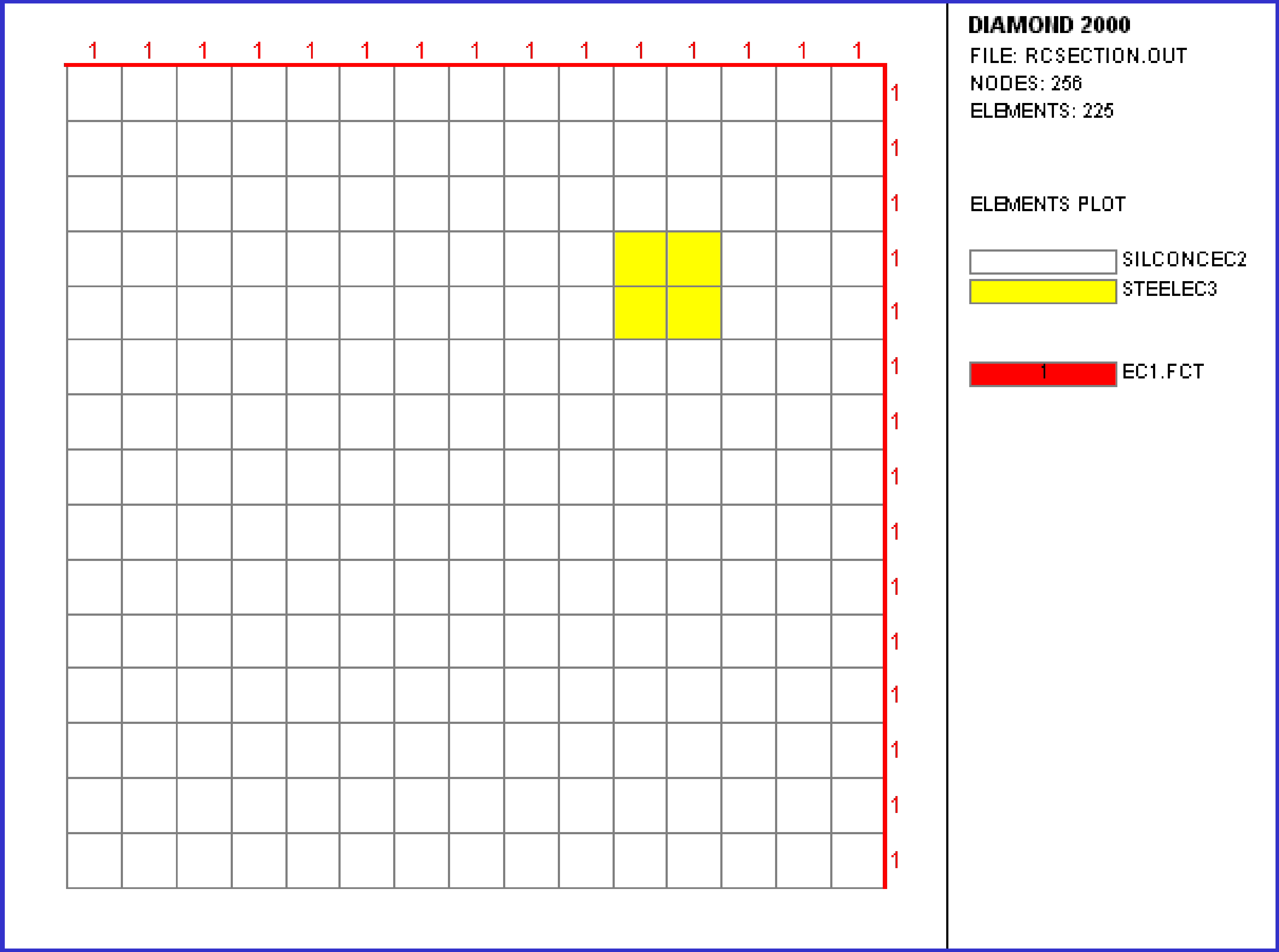
True section *Matching* *Discretised section*

⇒**The discretised section is an approximation of the real section**



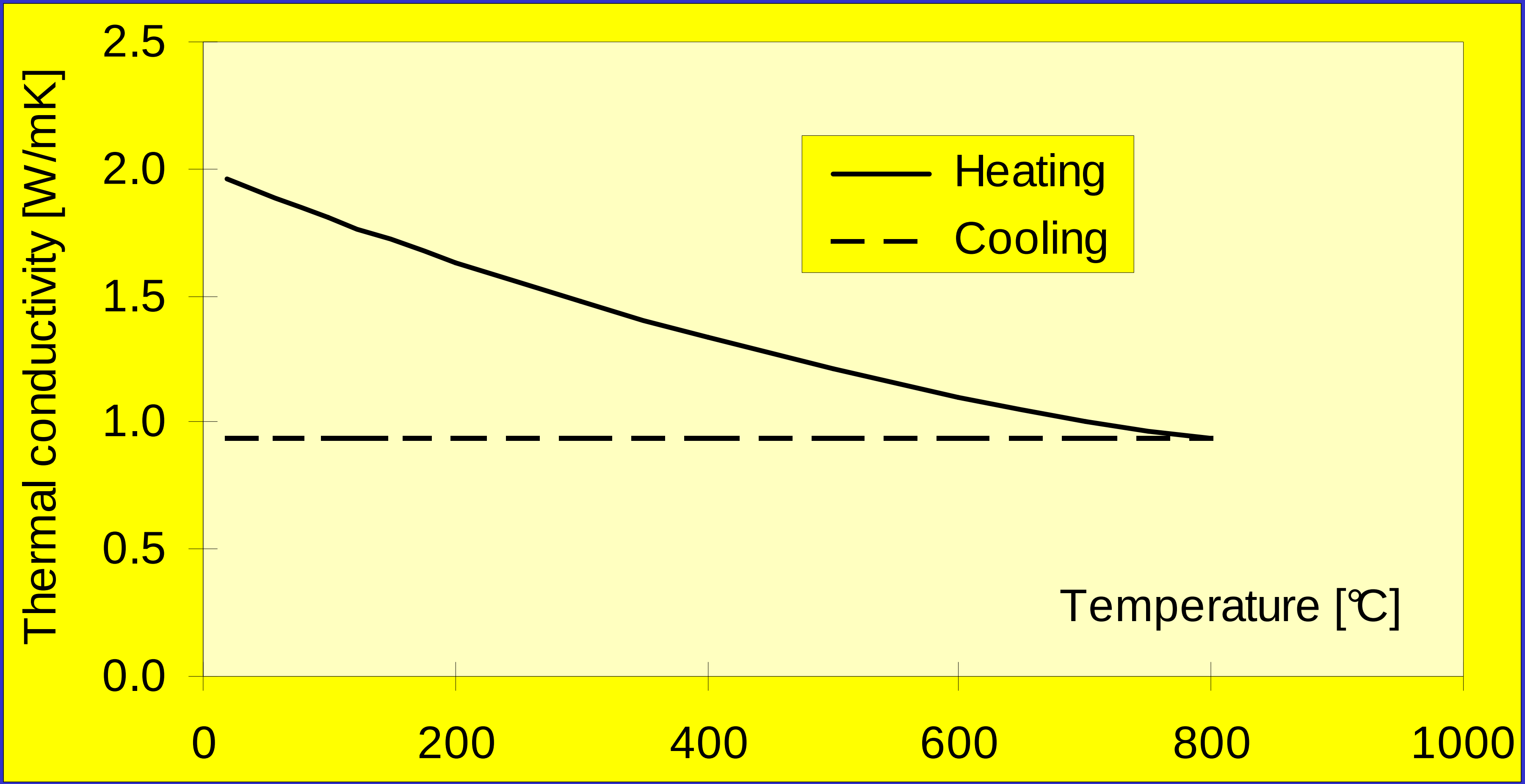
Same section.
Different discretisation.
⇒Different results

Note: the results tend toward the true solution when the size of the elements tends toward 0

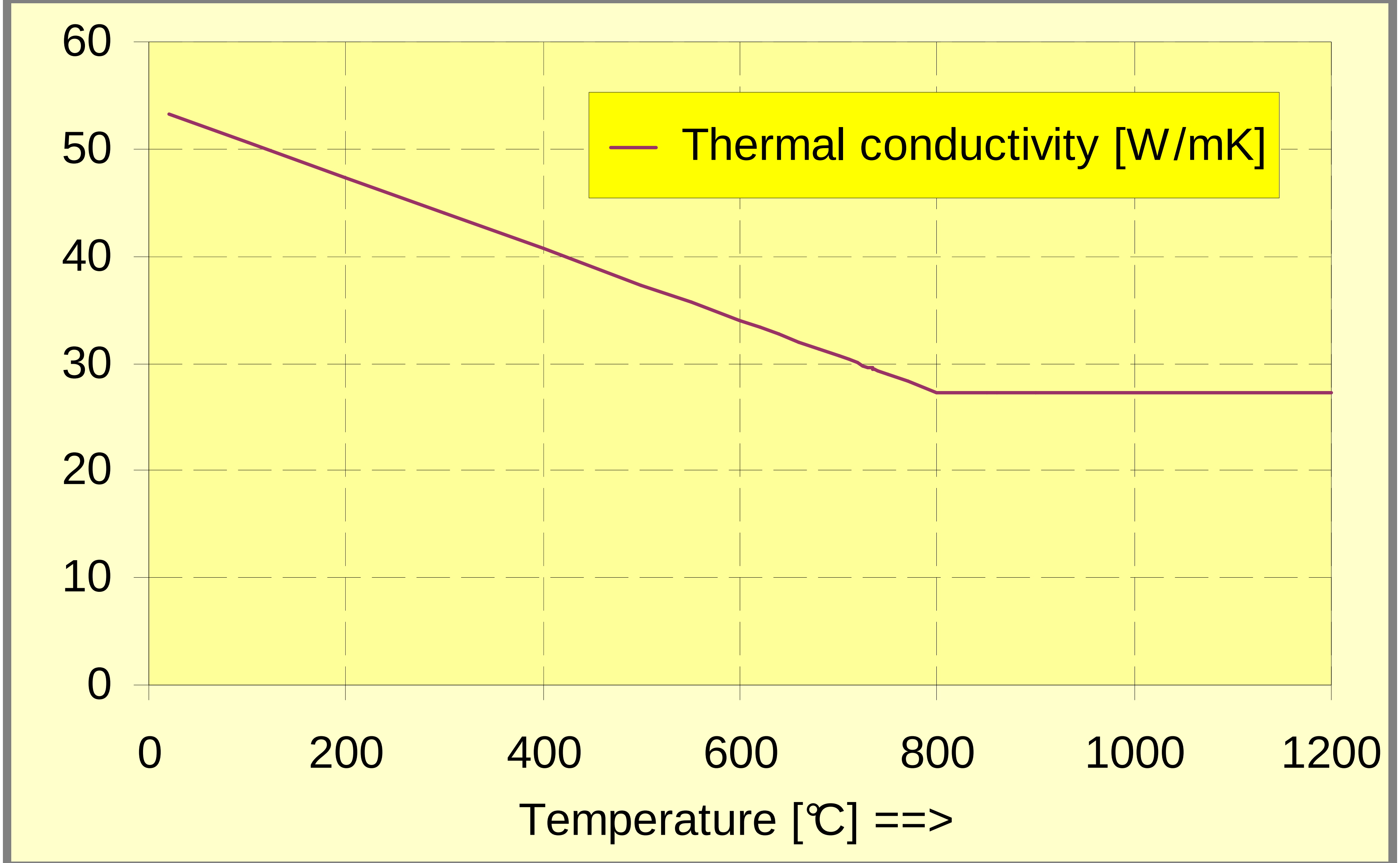


Example of a very simple discretisation

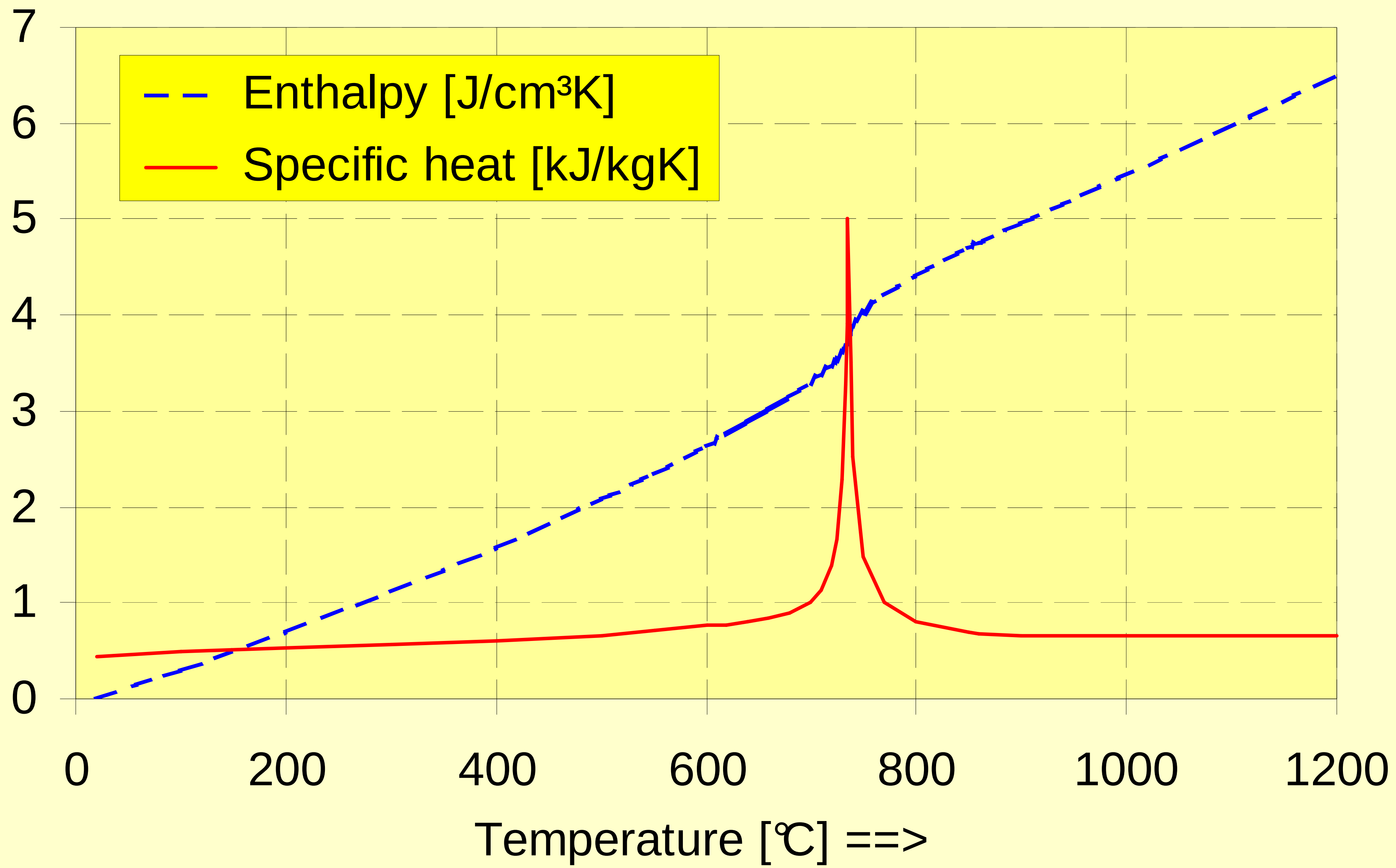
¼ of a 30 x 30 cm² reinforced concrete section



Non linear thermal properties are used.
Here, thermal conductivity of concrete
(non reversible during cooling).



Thermal conductivity of steel



Specific heat of steel

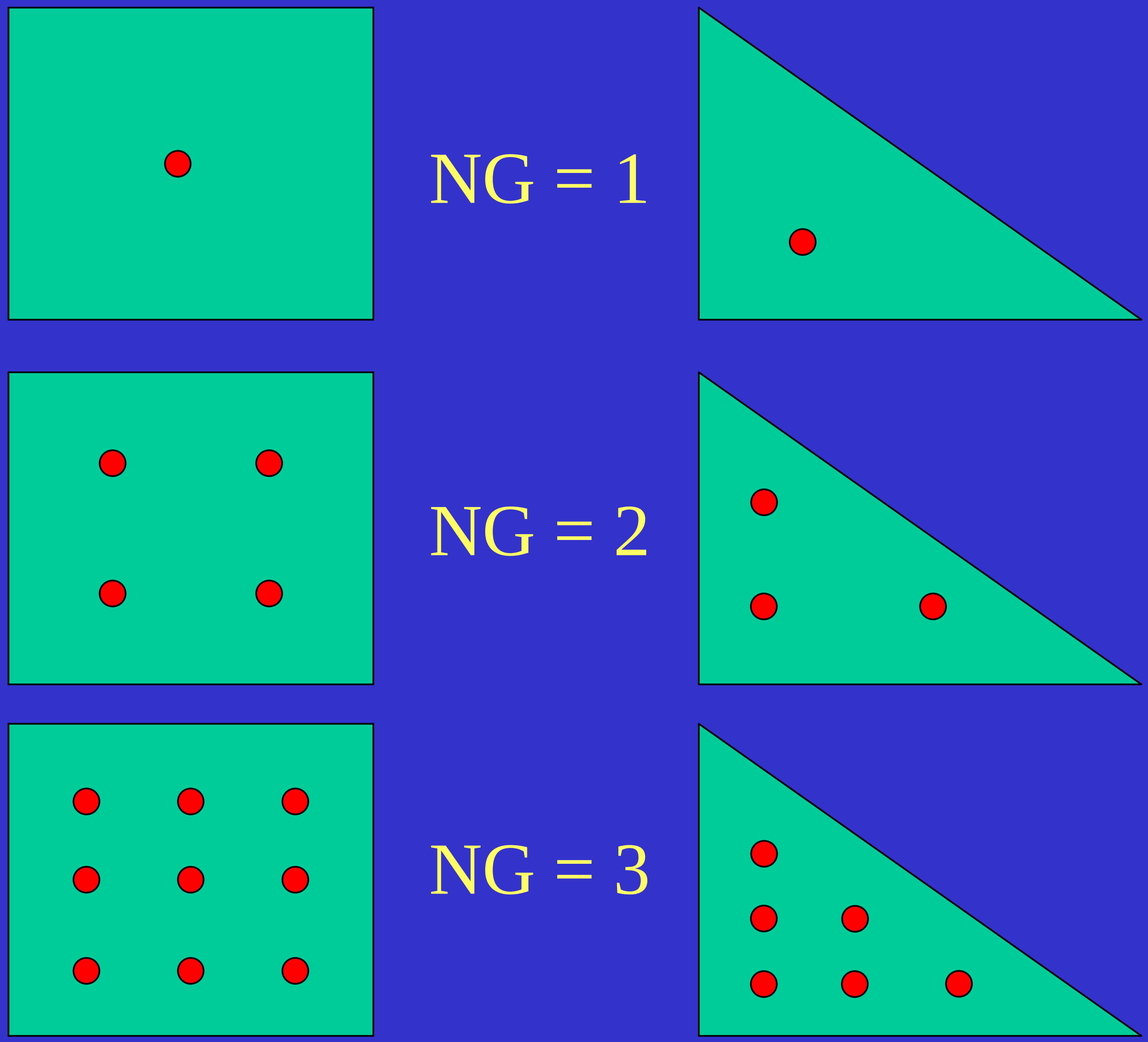
The local equilibrium equation for conduction is

$$\left(k\frac{\partial^2 T}{\partial x^2} + k\frac{\partial^2 T}{\partial y^2} \right) + Q = 0$$

It is transformed in an element equilibrium equation.

$$[K]\{T\} \quad = \quad \{q\}$$

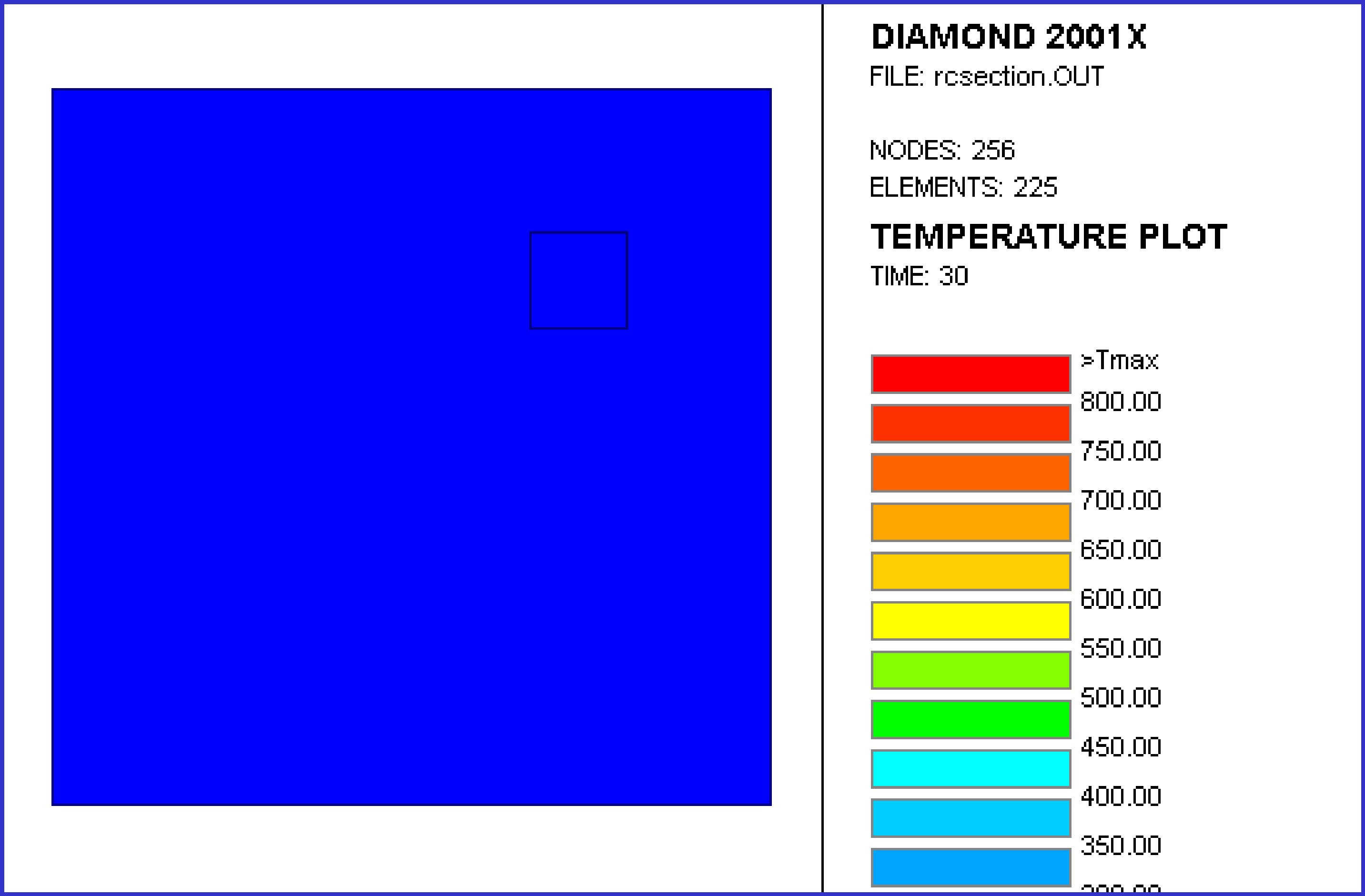
$$\begin{bmatrix} k_{1,1} & k_{1,2} & k_{1,3} & k_{1,4} \\ & k_{2,2} & k_{2,3} & k_{2,4} \\ & & k_{3,3} & k_{3,4} \\ Sym & & & k_{4,4} \end{bmatrix} \begin{Bmatrix} T_1 \\ T_2 \\ T_3 \\ T_4 \end{Bmatrix} = \begin{Bmatrix} q_1 \\ q_2 \\ q_3 \\ q_4 \end{Bmatrix}$$

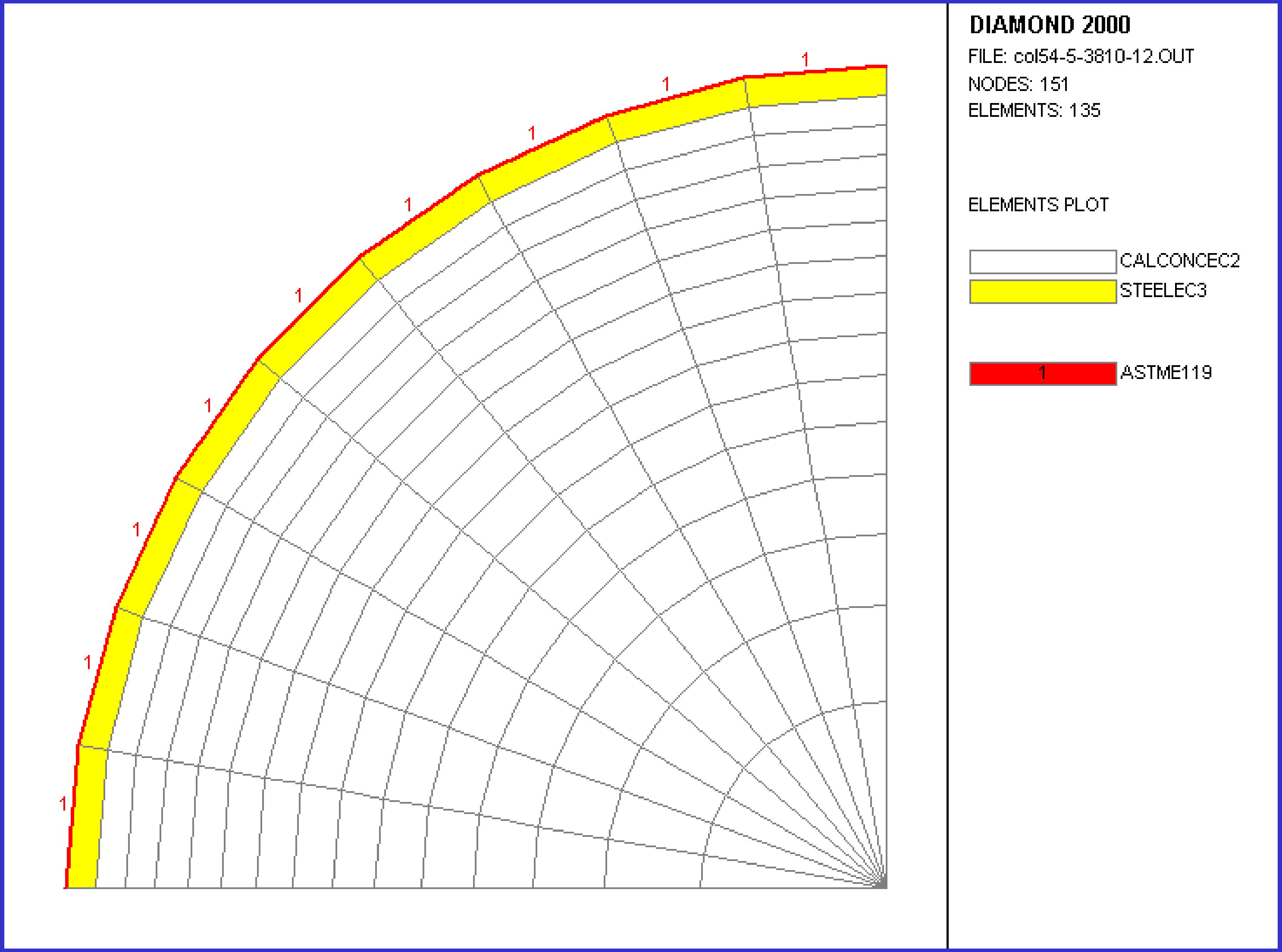


Integration of the thermal properties on the surface:
Numerical method of Gauss

The transient temperature distribution is evaluated.

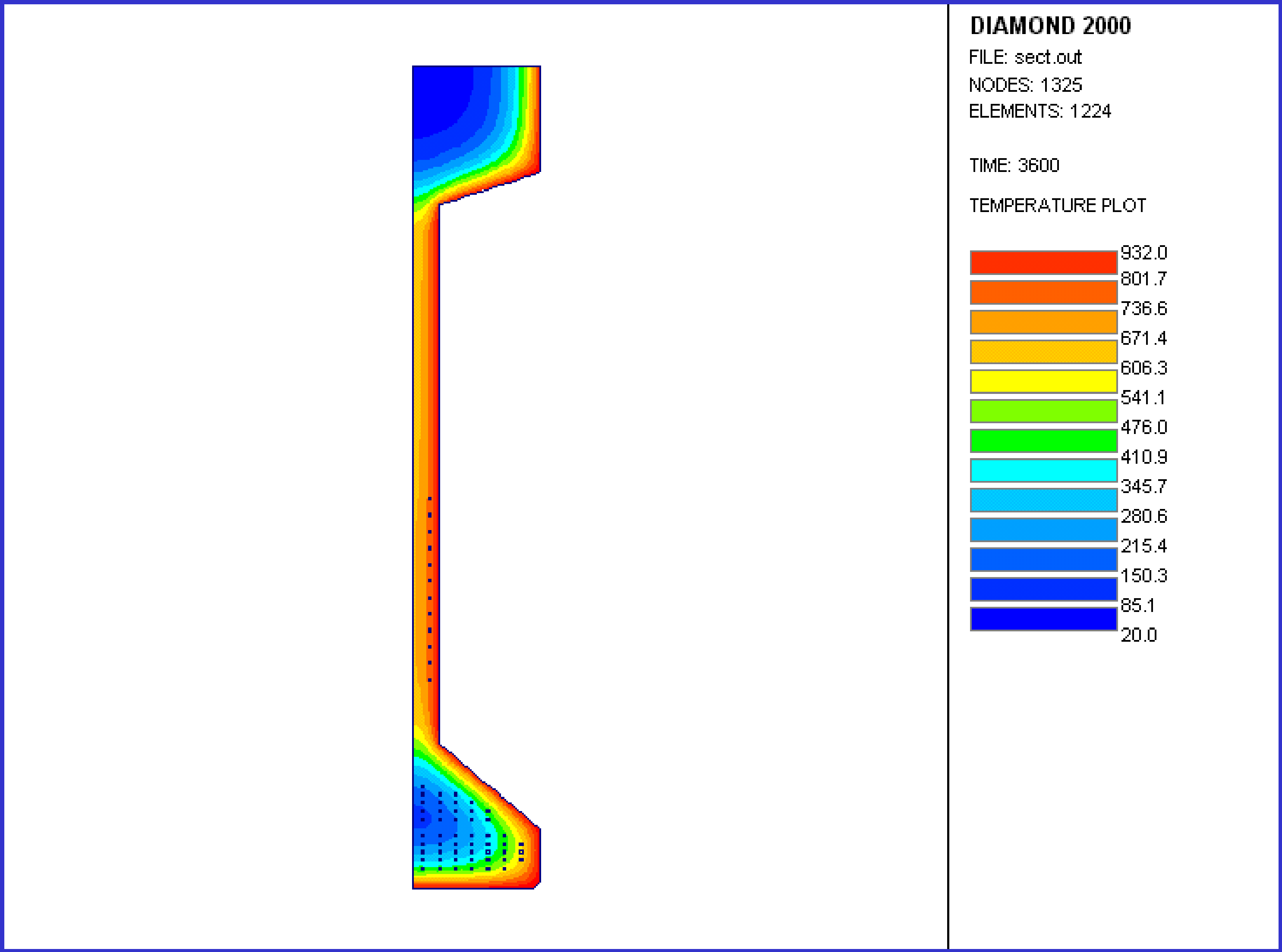
Here under a natural fire (peak temperature after 3600 sec).





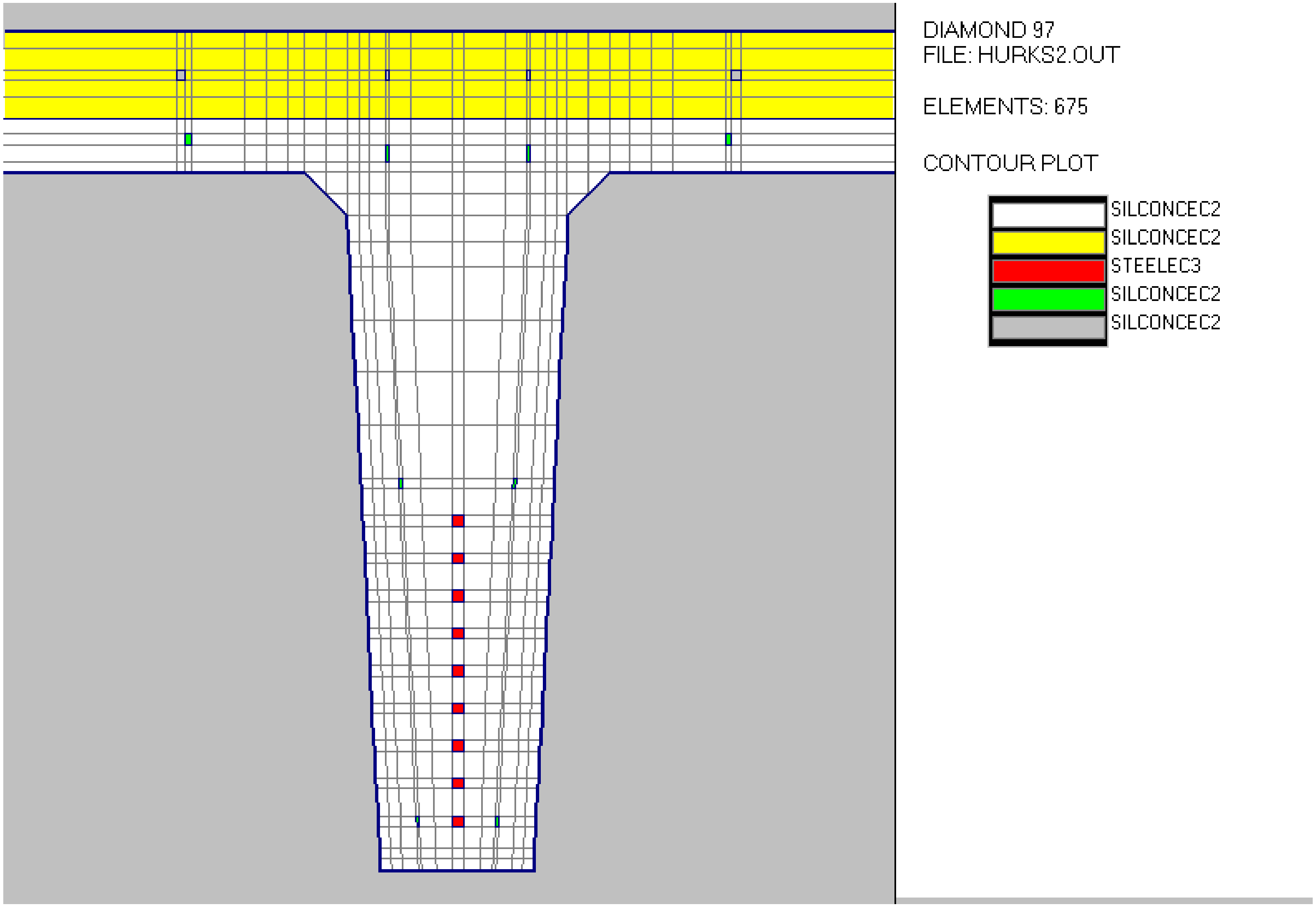
Concrete Filled Steel Section

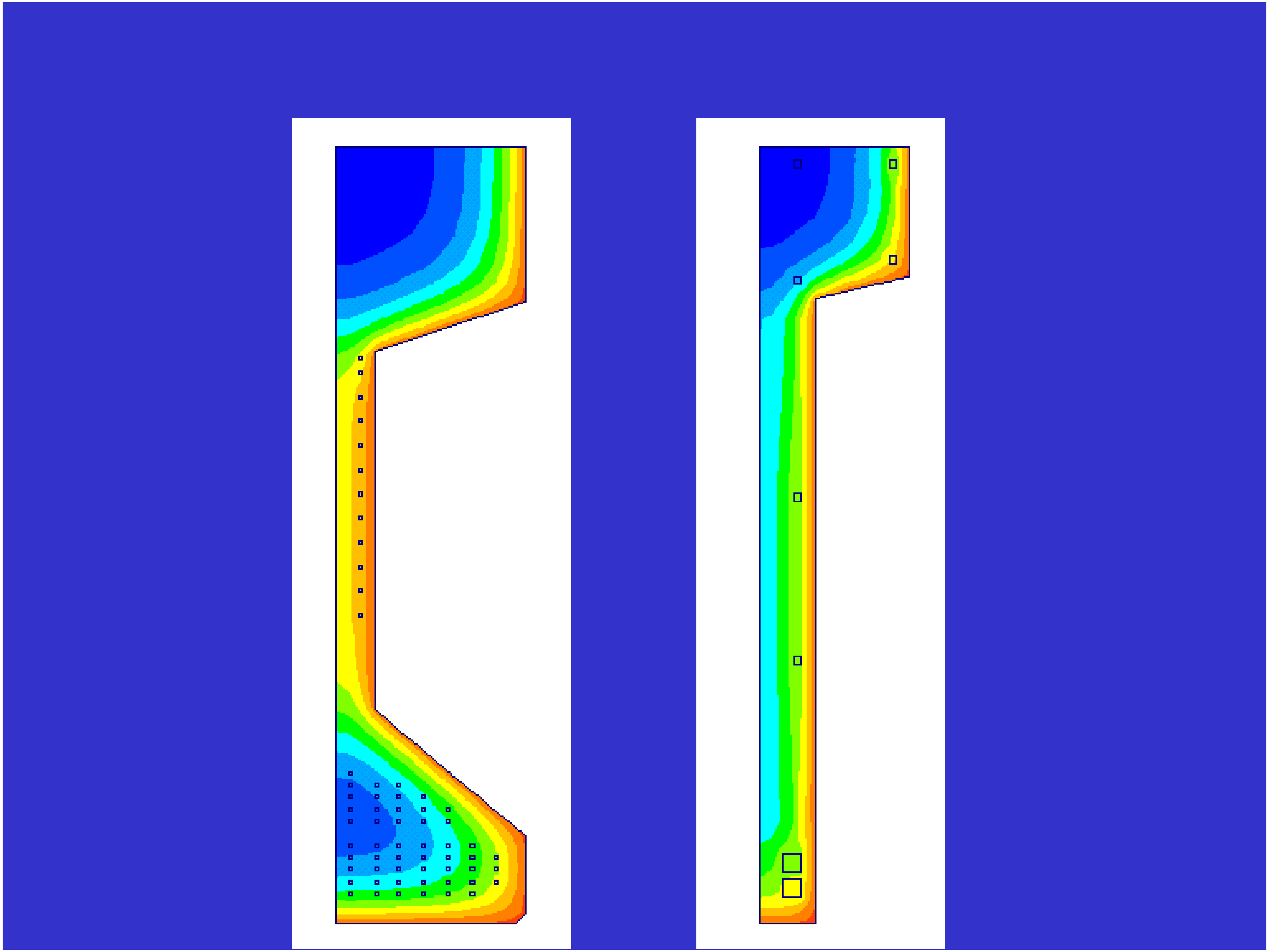
(*courtesy N.R.C*. Ottawa)

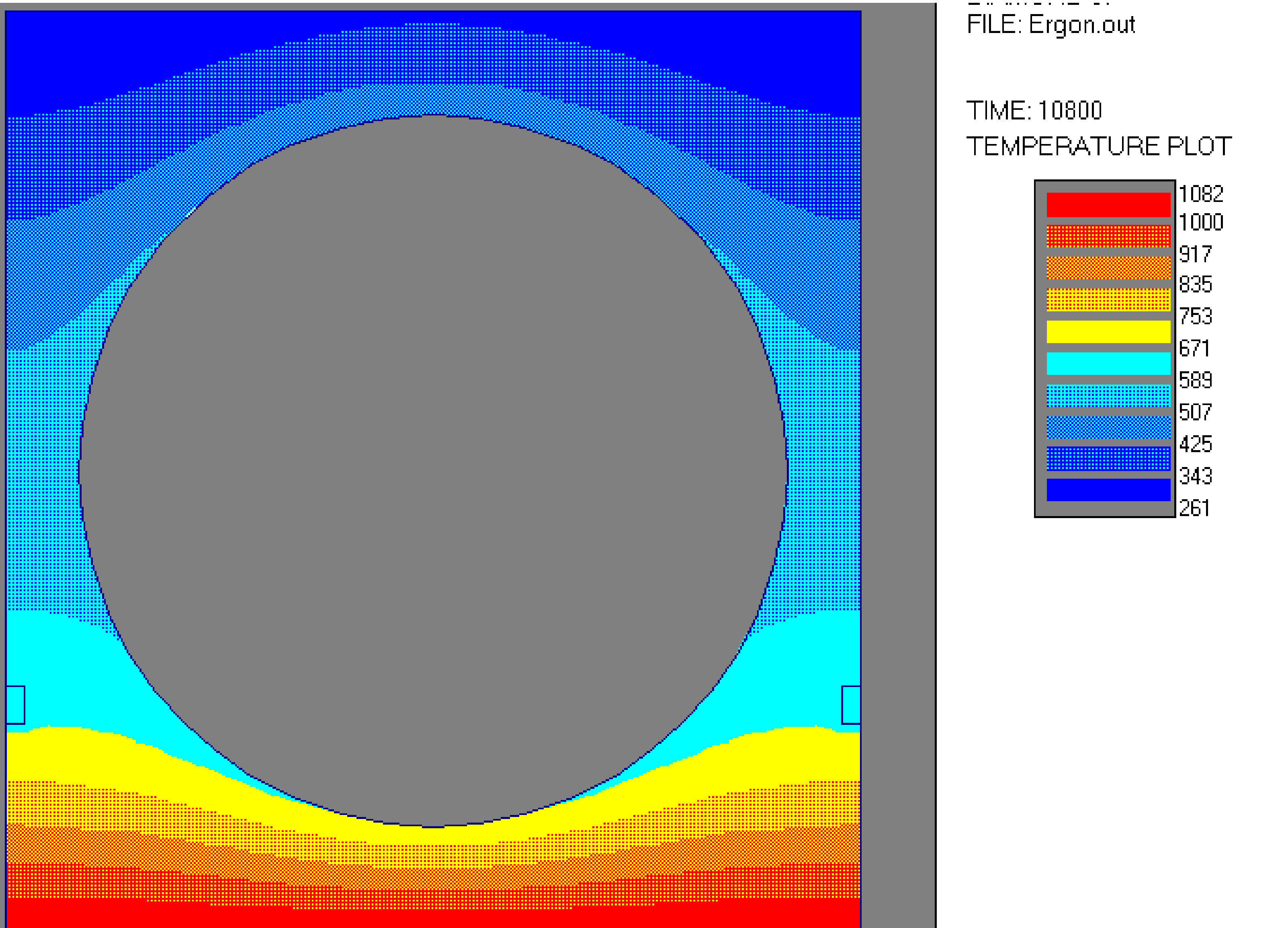


Prestressed concrete section

TT prestressed beam

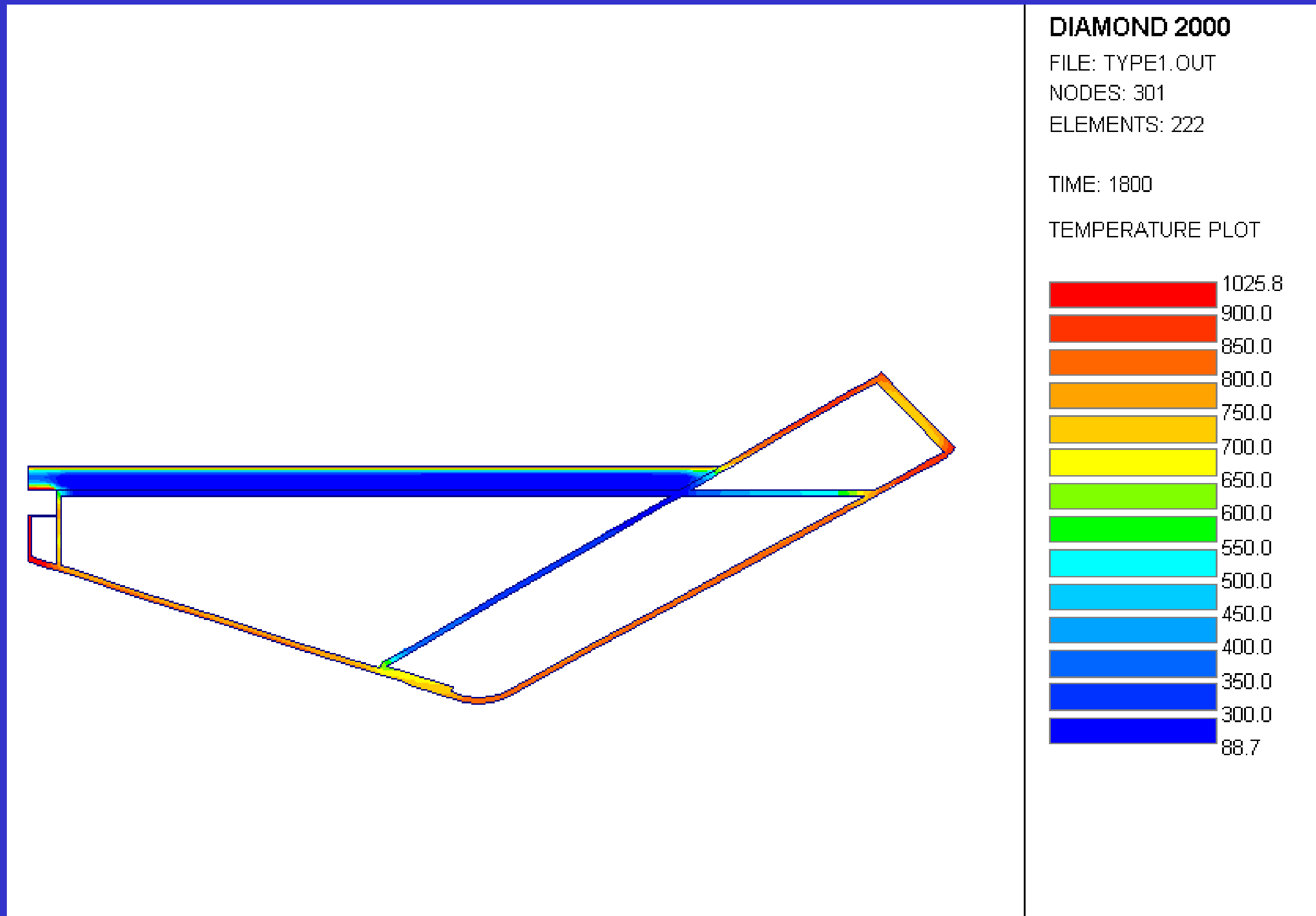




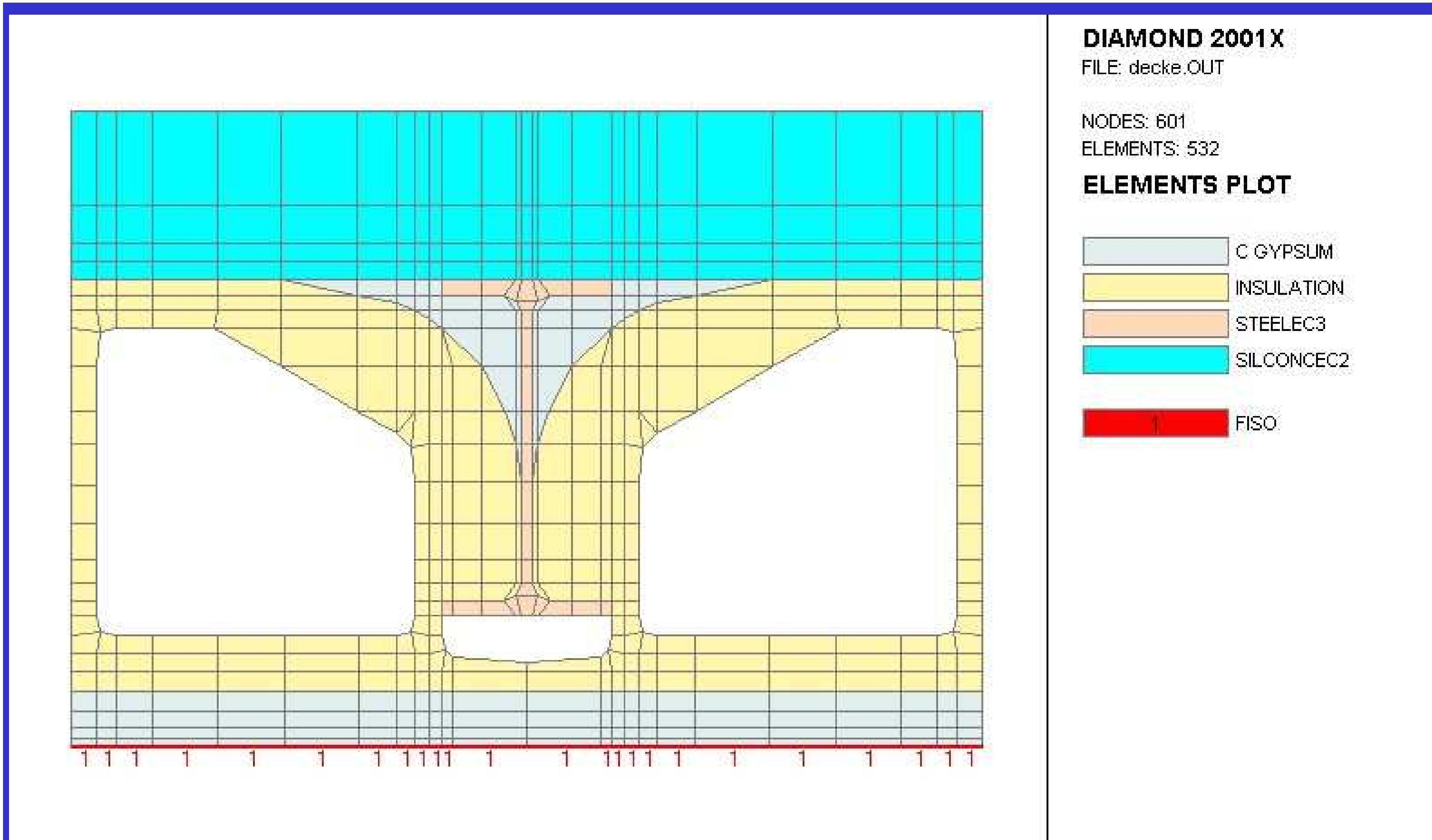


Radiation in the cavities is taken into account

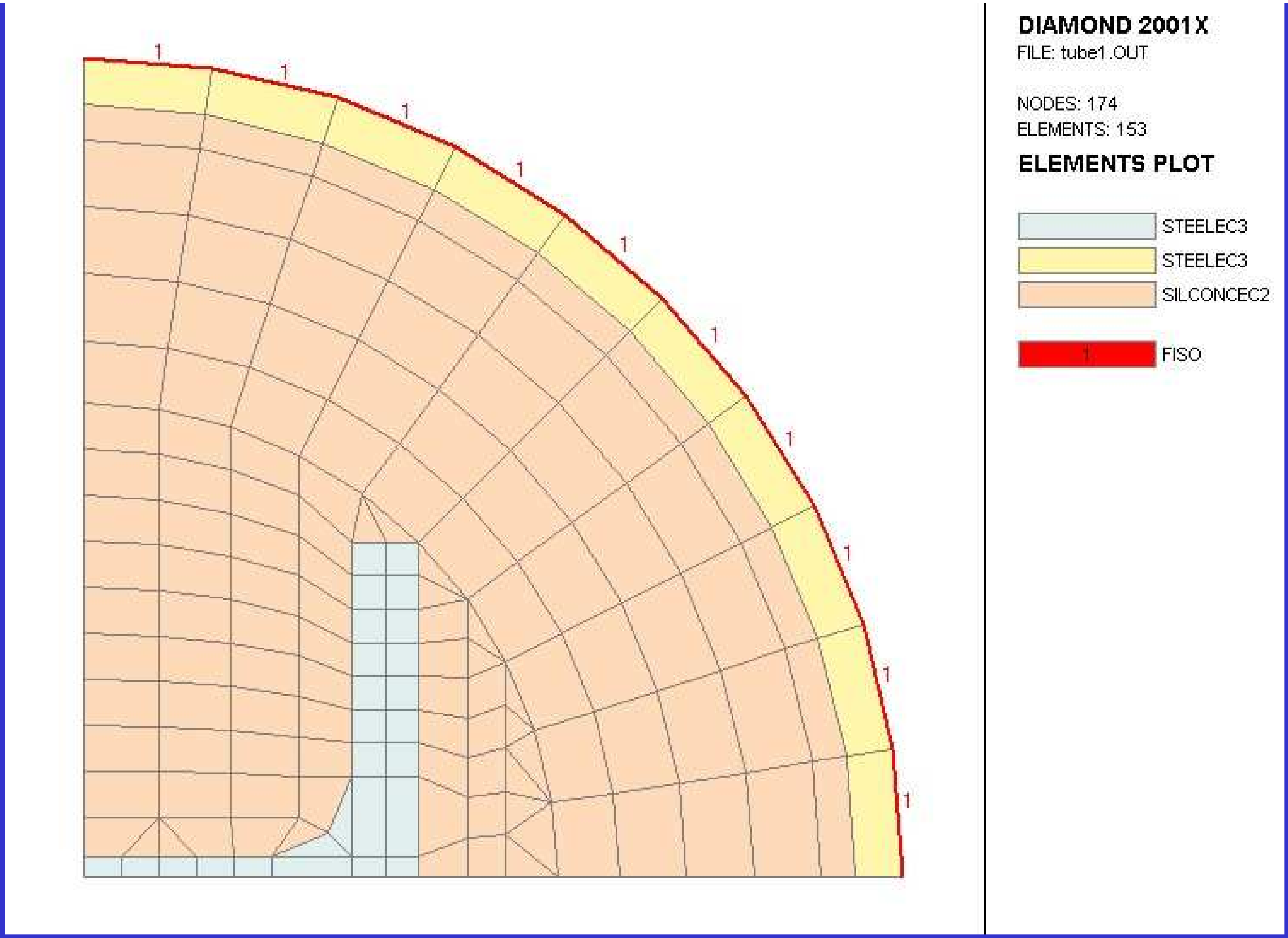
Concrete hollow core slab



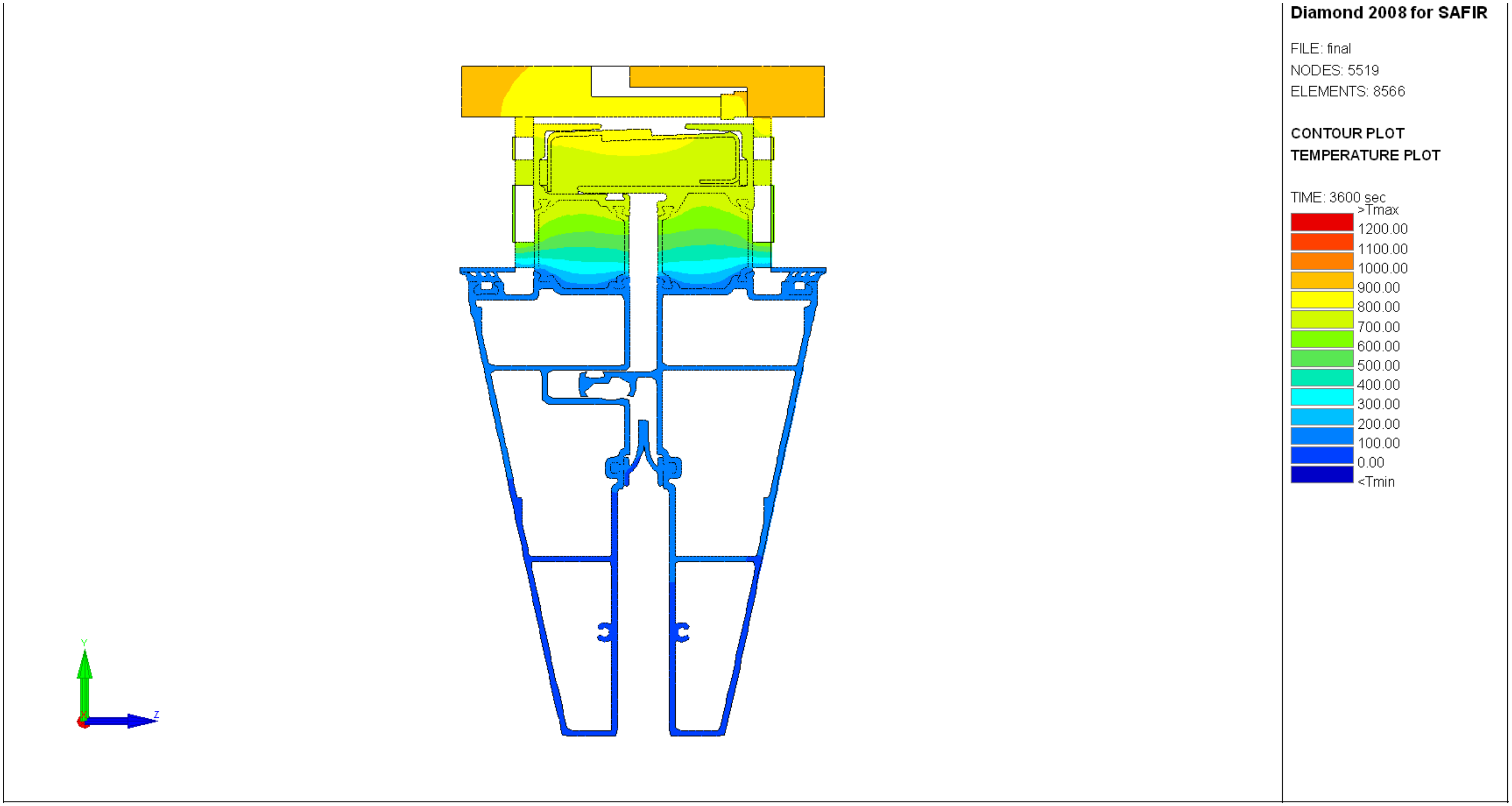
T.G.V. railway station in Liege (courtesy Bureau Greisch).
Main steel beam with concrete slab.



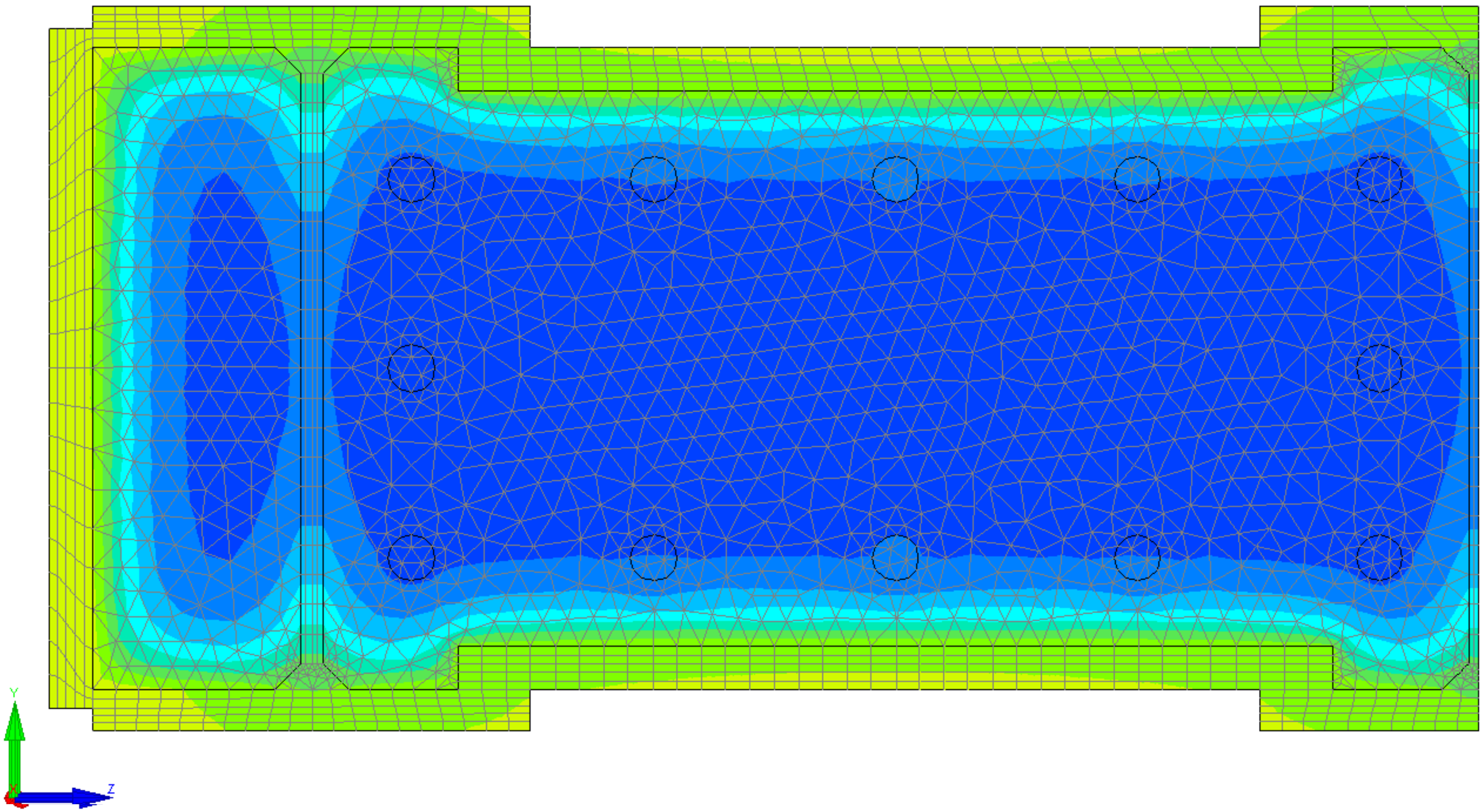
Old floor system; steel I beams and precast voussoirs
Courtesy: Lenz Weber, Frankfurt



Steel H section in a steel tube filled with concrete

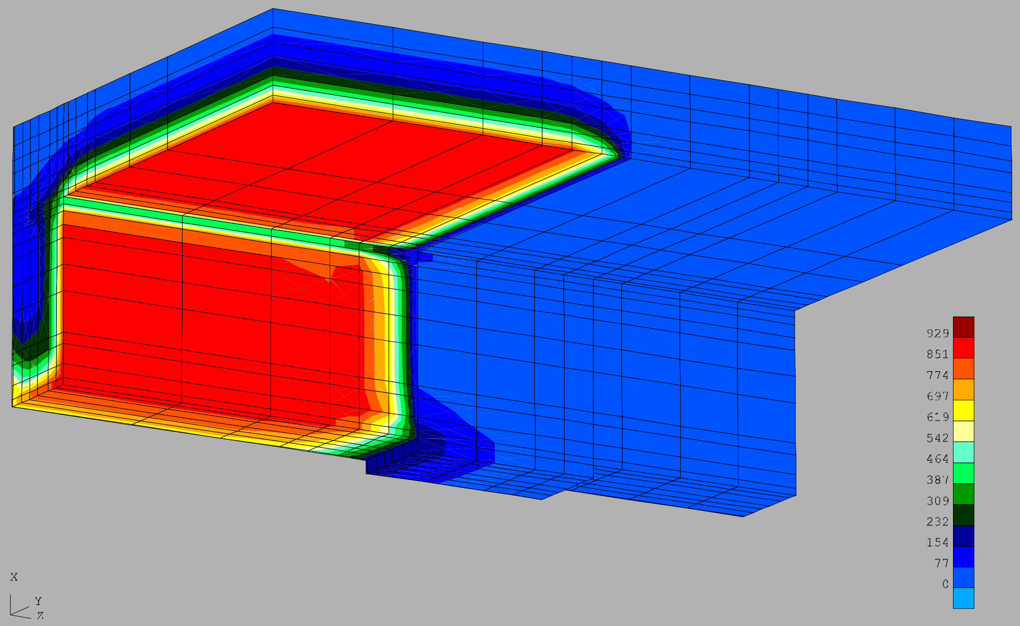


Window frame (courtesy: Permasteelisa)

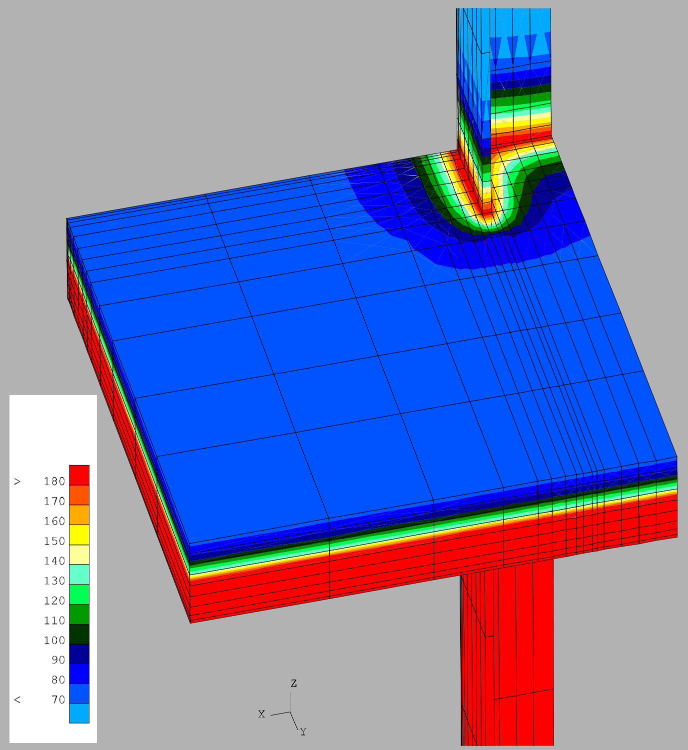


Composite steel-concrete columns (1/2)
Courtesy: Technum

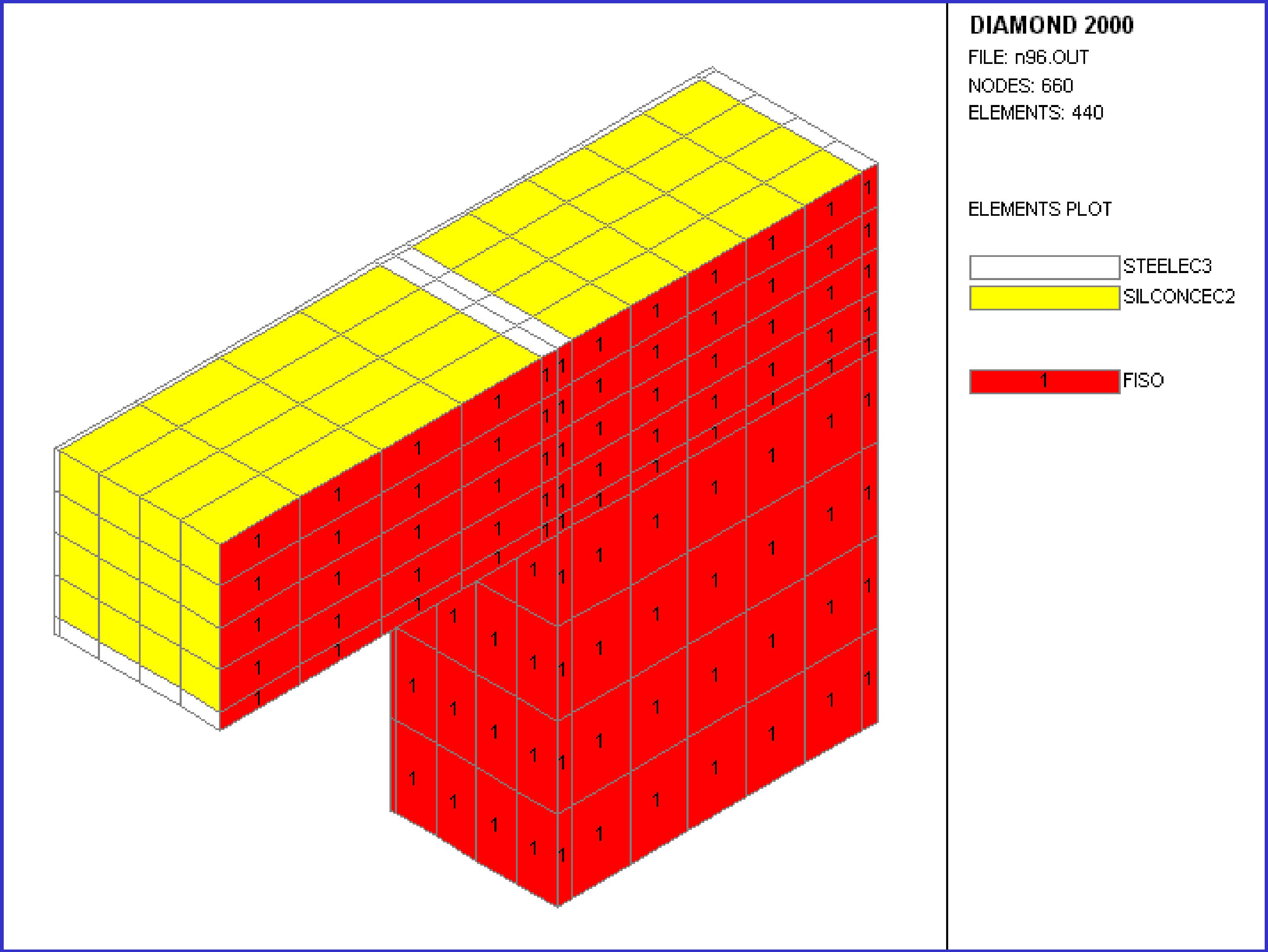
Composite beam partly heated



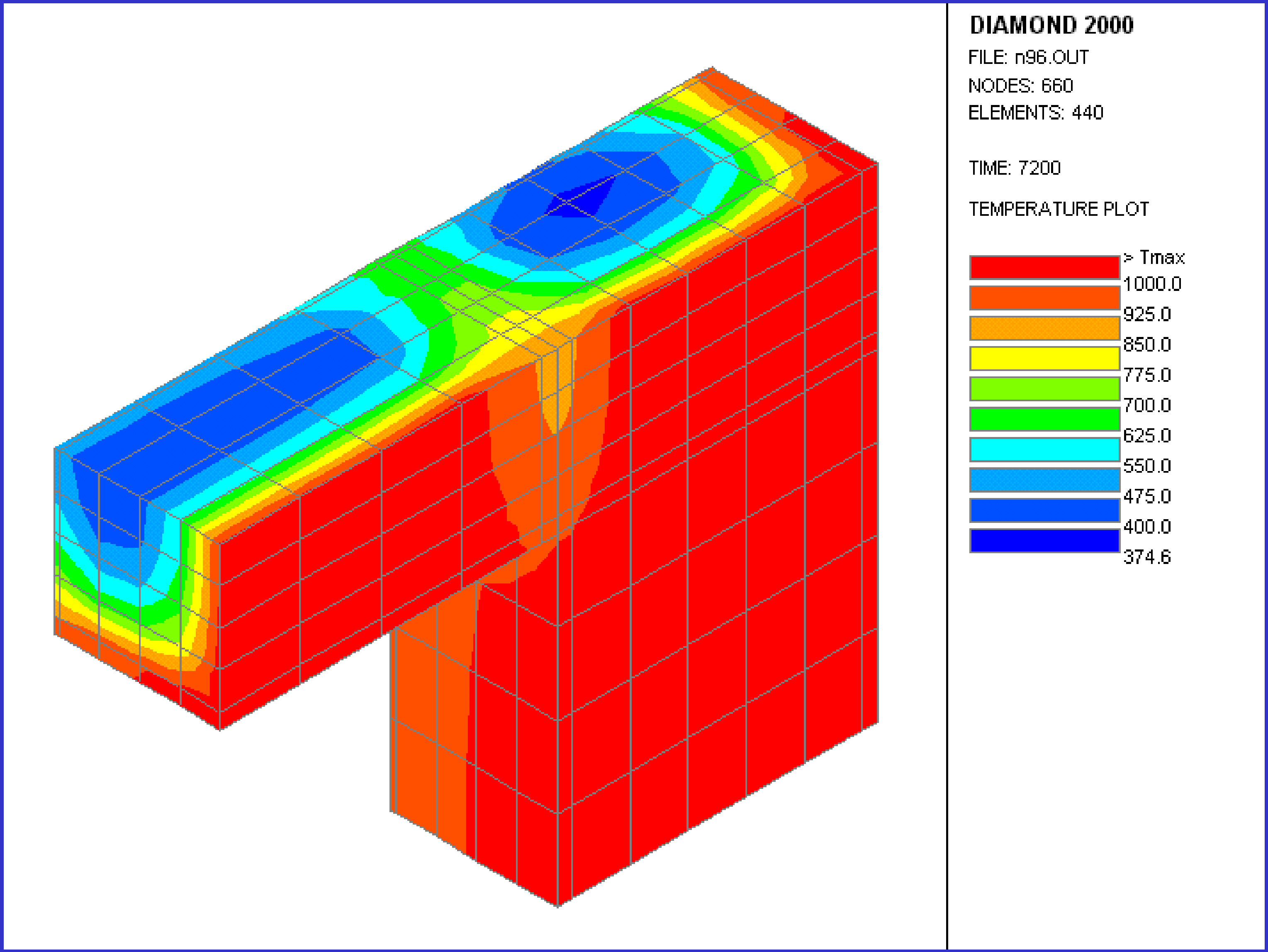
Steel column through a concrete slab



3D examples

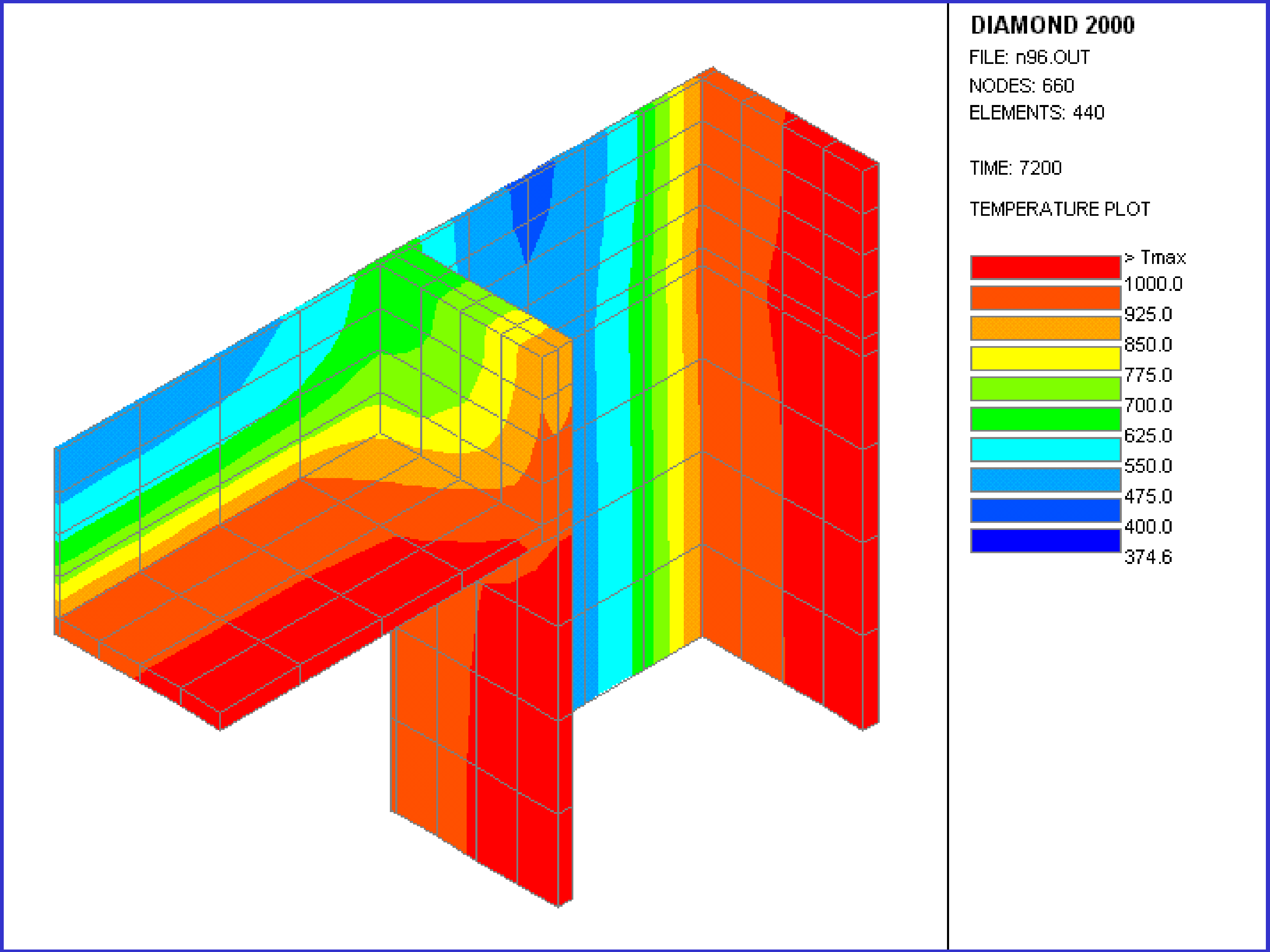


Composite steel-concrete joint
Discretisation



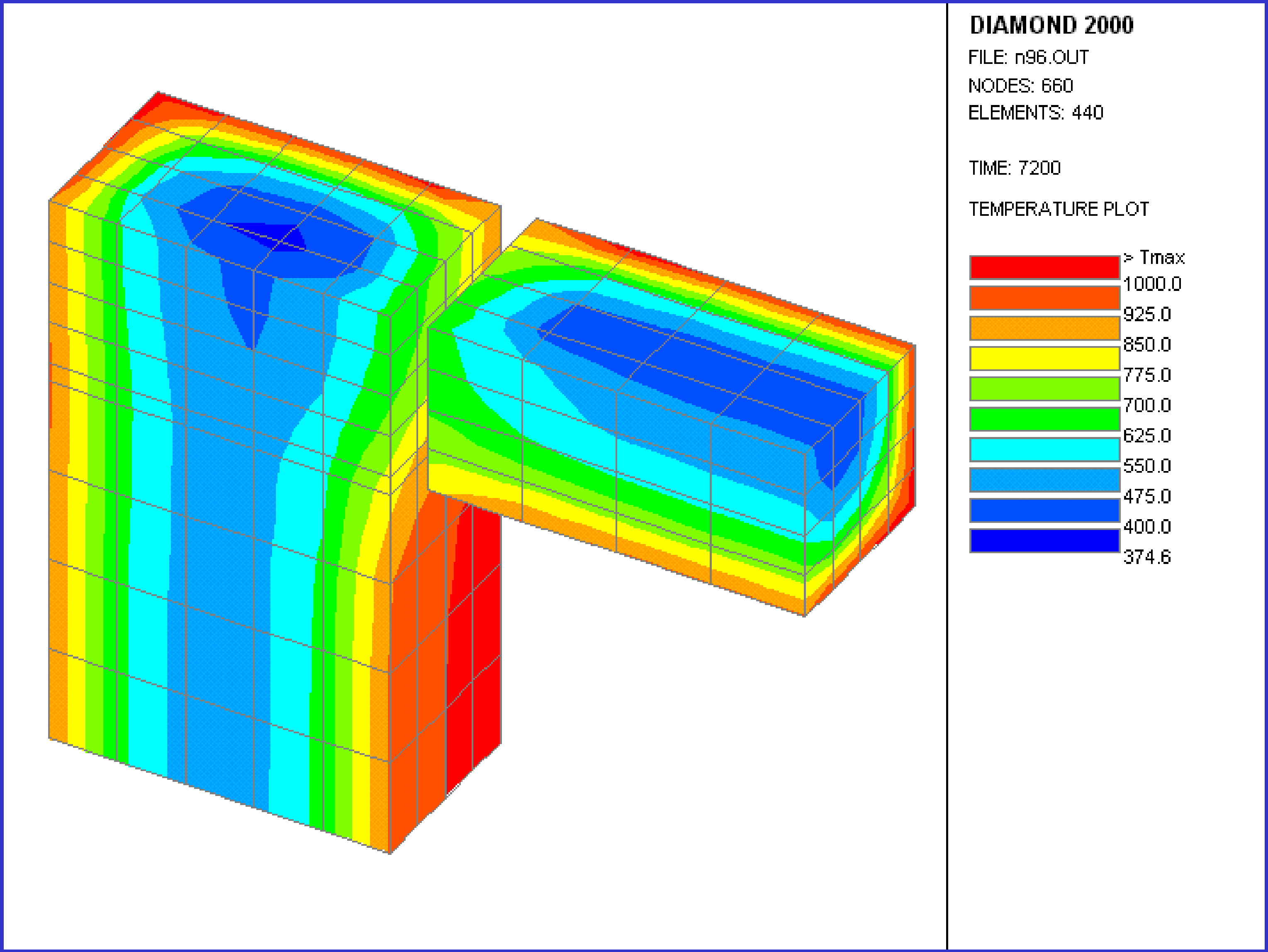
Composite steel-concrete joint

Temperatures on the surface

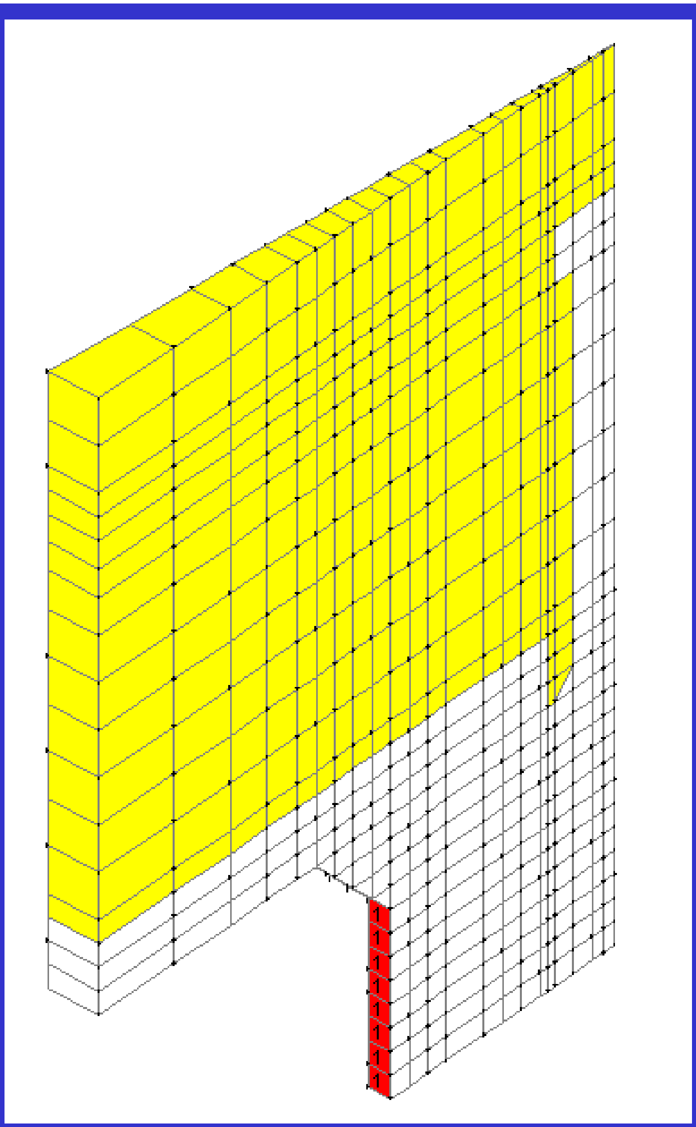


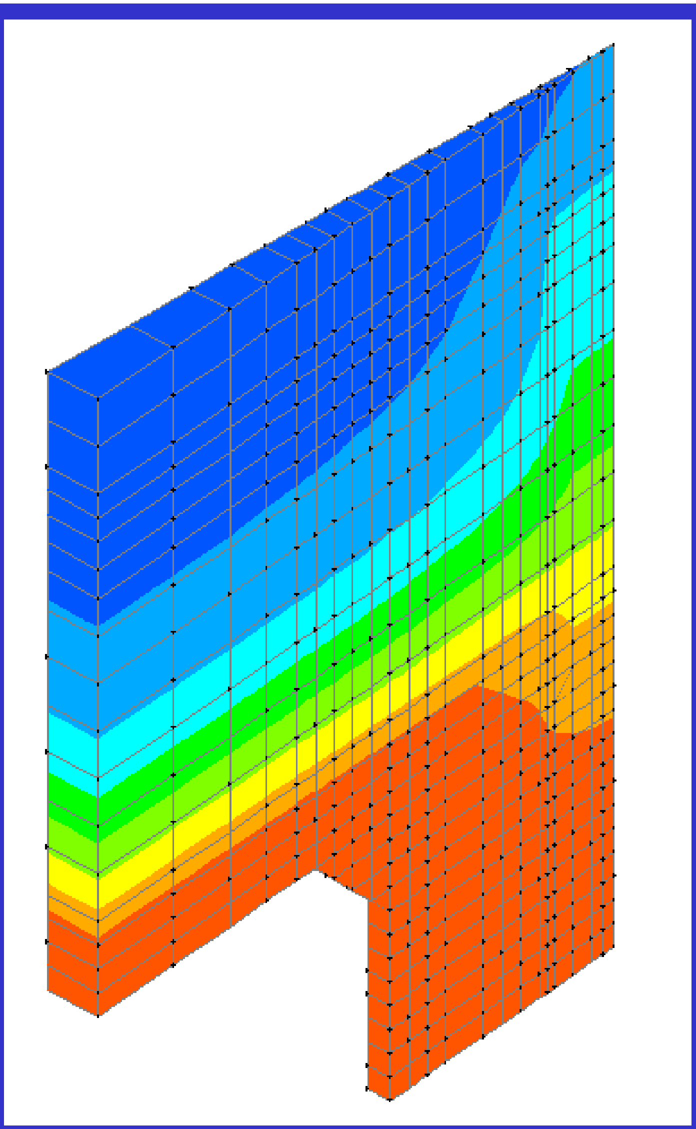
Composite steel-concrete joint

Temperatures on the steel elements (concrete is transparent)



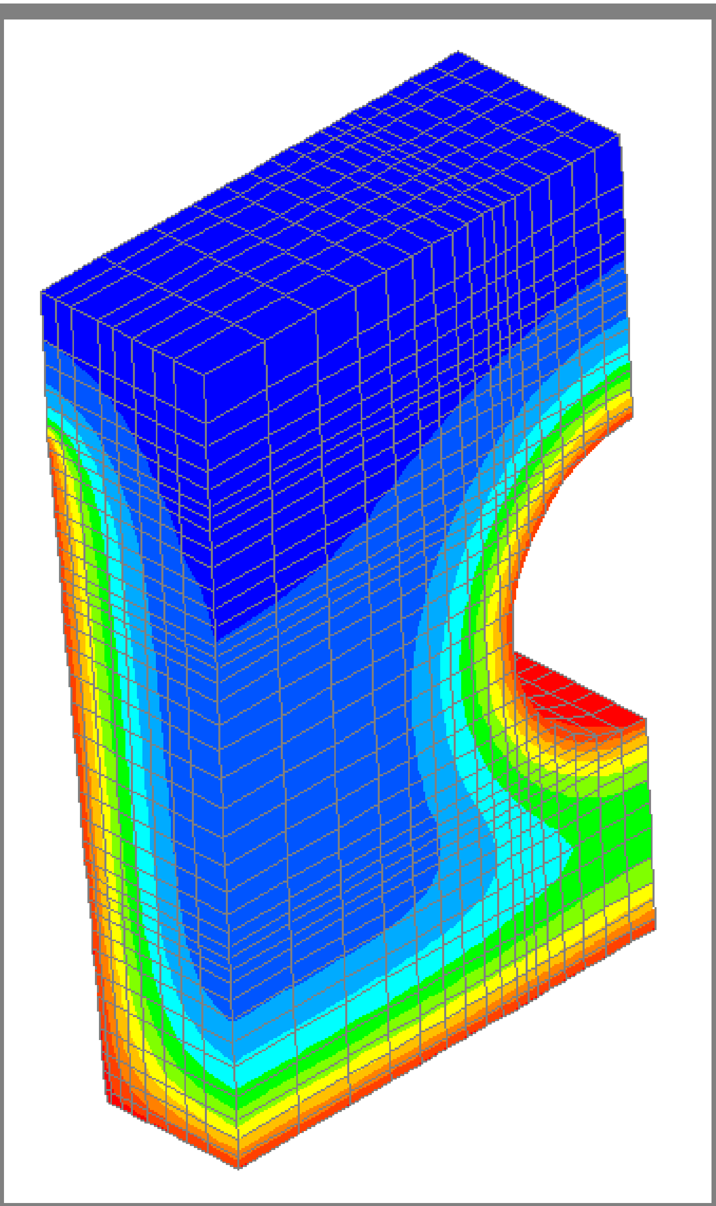
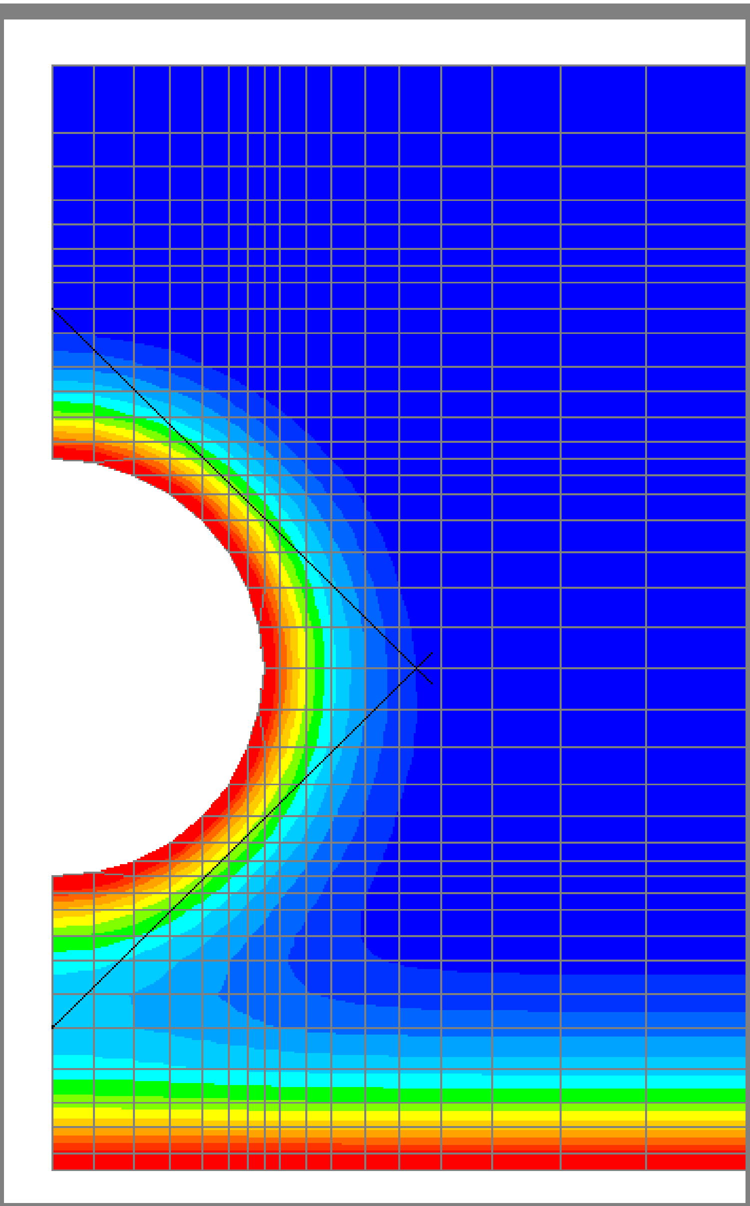
Composite steel-concrete joint
Temperatures on the concrete elements (steel transparent)





Project Team EN 1994-1-2 (Eurocode 4)

Steel stud on a thick plate (axi-symetric problem)

Concrete beam (courtesy *Halfkann & Kirchner*)

Transmission of the shear force around the holes

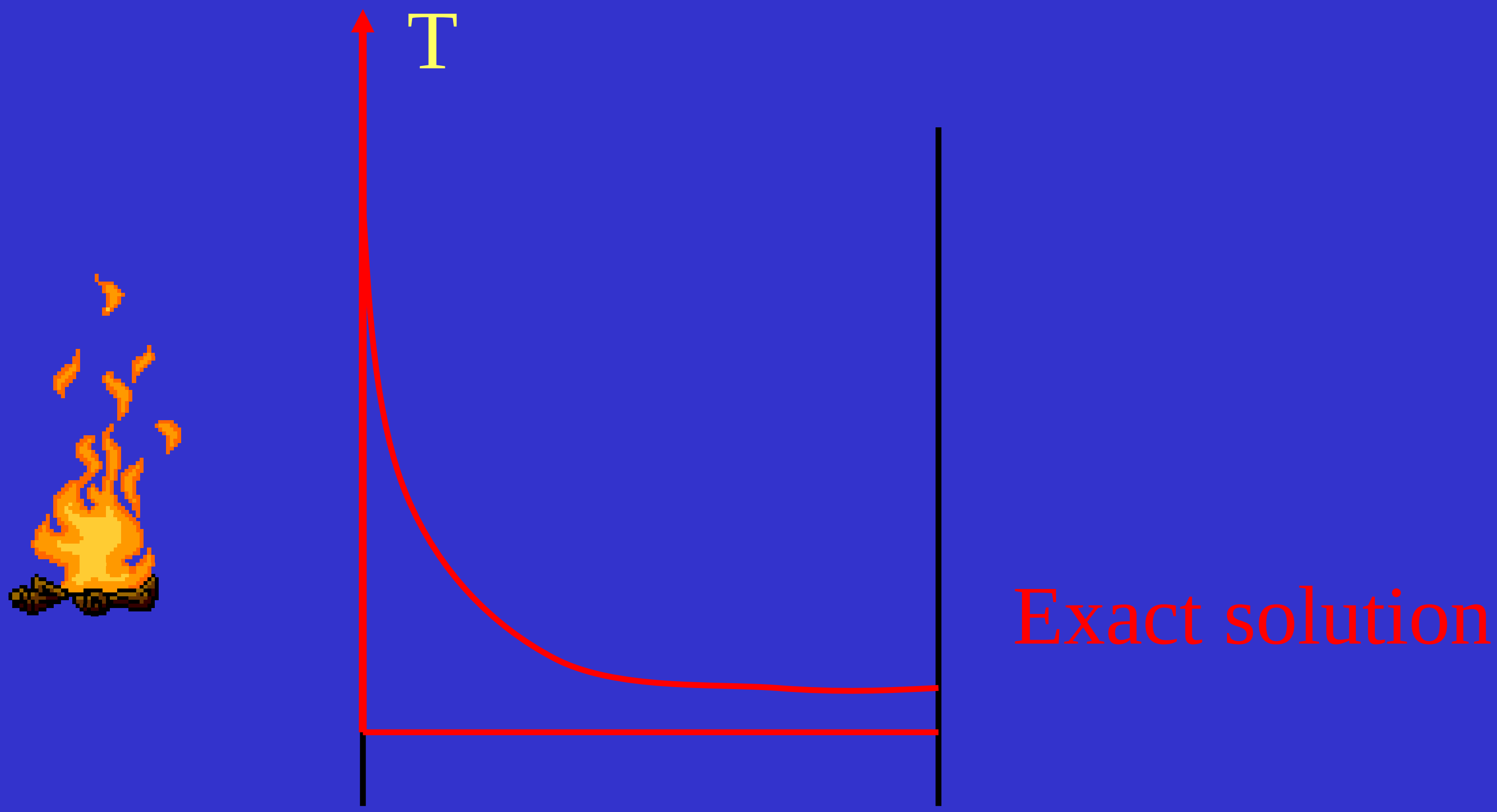
Step 2. Thermal response : limitations

- Free water – the evaporation is taken into account, but not the migration.
- Internal cavities only in 2D sections.
- Perfect conductive contact between the materials.
- Fixed geometry (spalling! Now taken into account, but not predicted, see advanced SAFIR course).
- Isotropic materials (no influence of cracking in concrete. Now orthotropic timber is considered).

Step 2. Thermal response : limitations

Linear elements.

Consequence: possible skin effects (spatial oscillations)

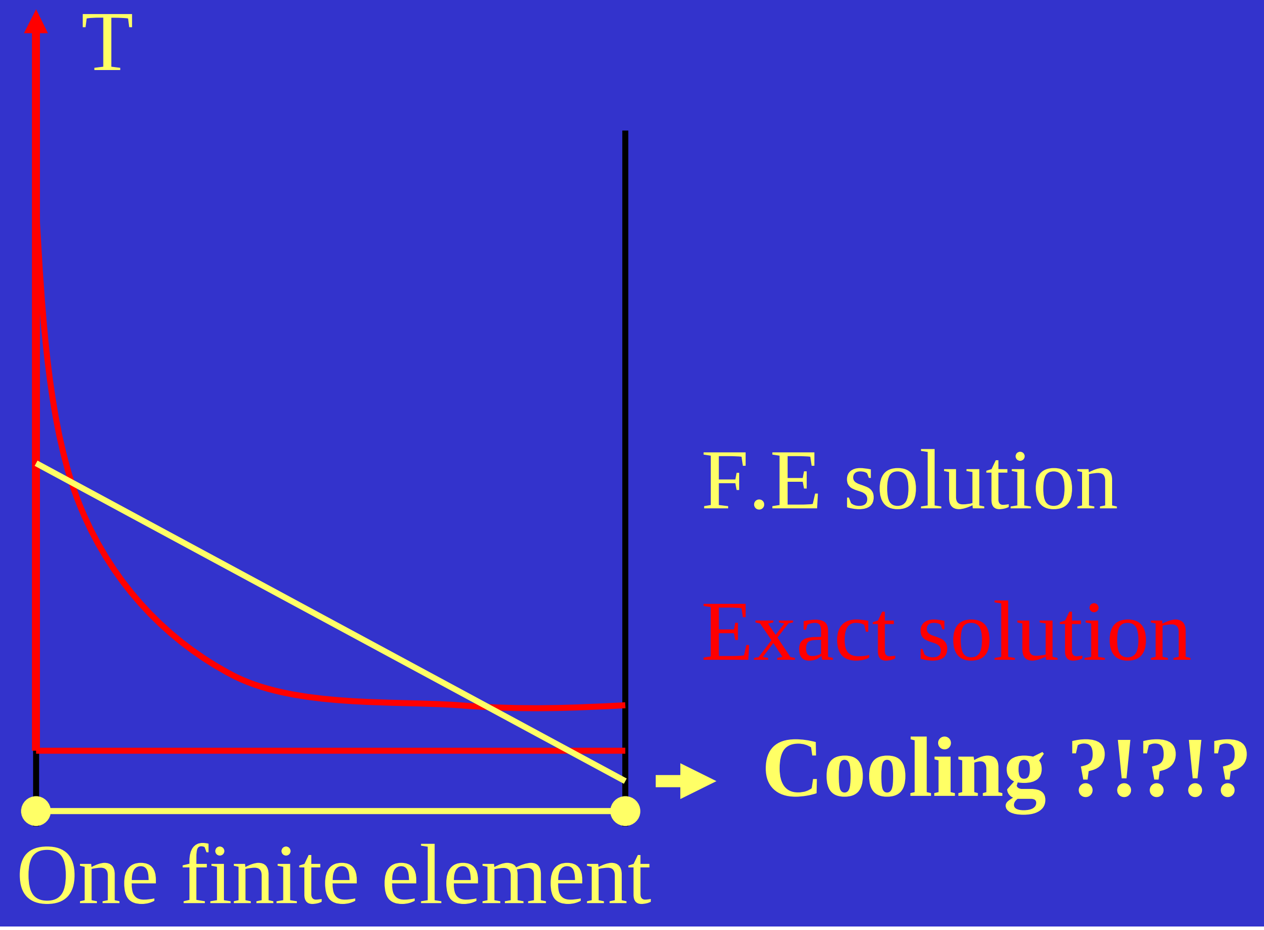


A wall (uniaxial heat flow)

Step 2. Thermal response : limitations

Linear elements.

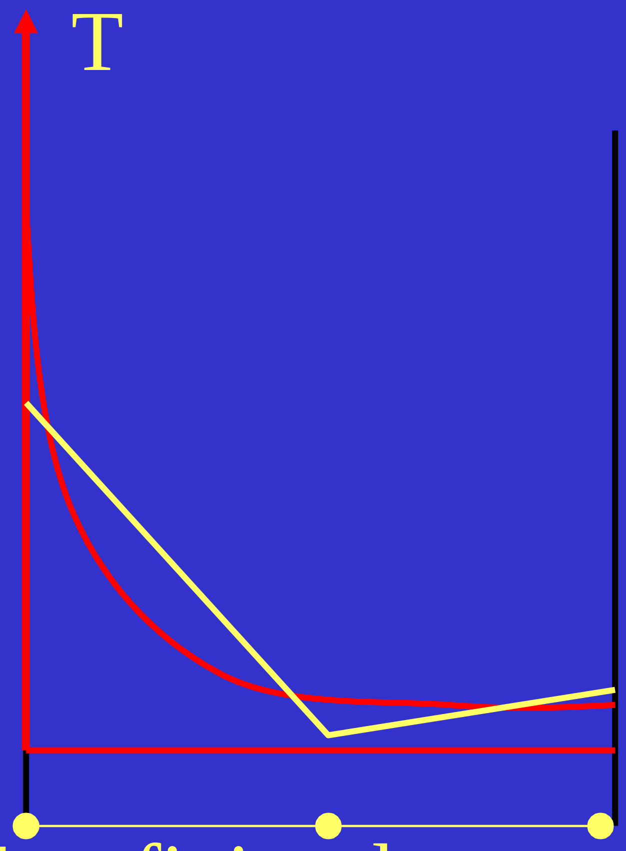
Consequence: possible skin effects (spatial oscillations)



Step 2. Thermal response : limitations

Linear elements.

Consequence: possible skin effects (spatial oscillations)



F.E solution

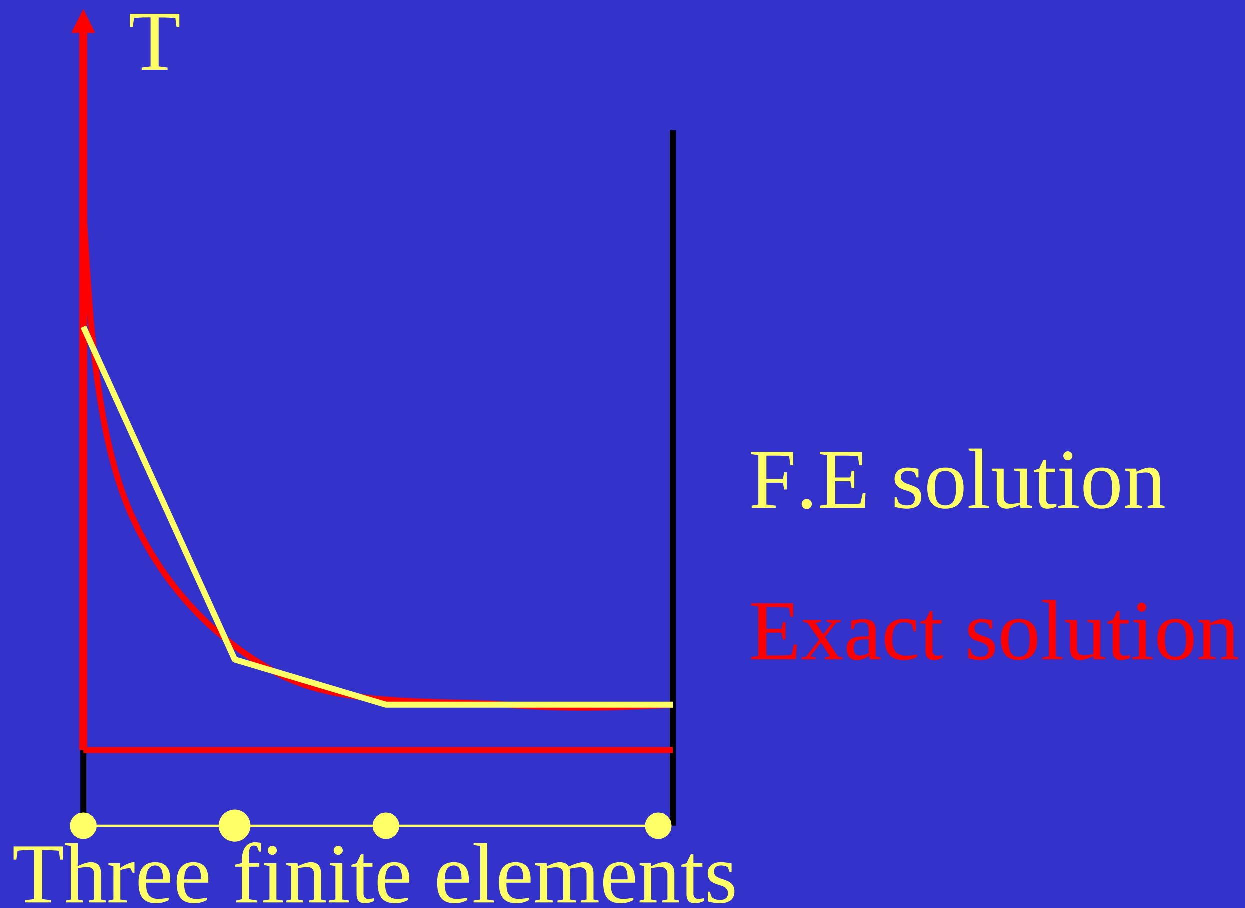
Exact solution

Two finite elements

Step 2. Thermal response : limitations

Linear elements.

Consequence: possible skin effects (spatial oscillations)



Step 2. Thermal response : limitations

Linear elements.

Consequence: possible skin effects (spatial oscillations)

Solution:

The mesh must not be too crude

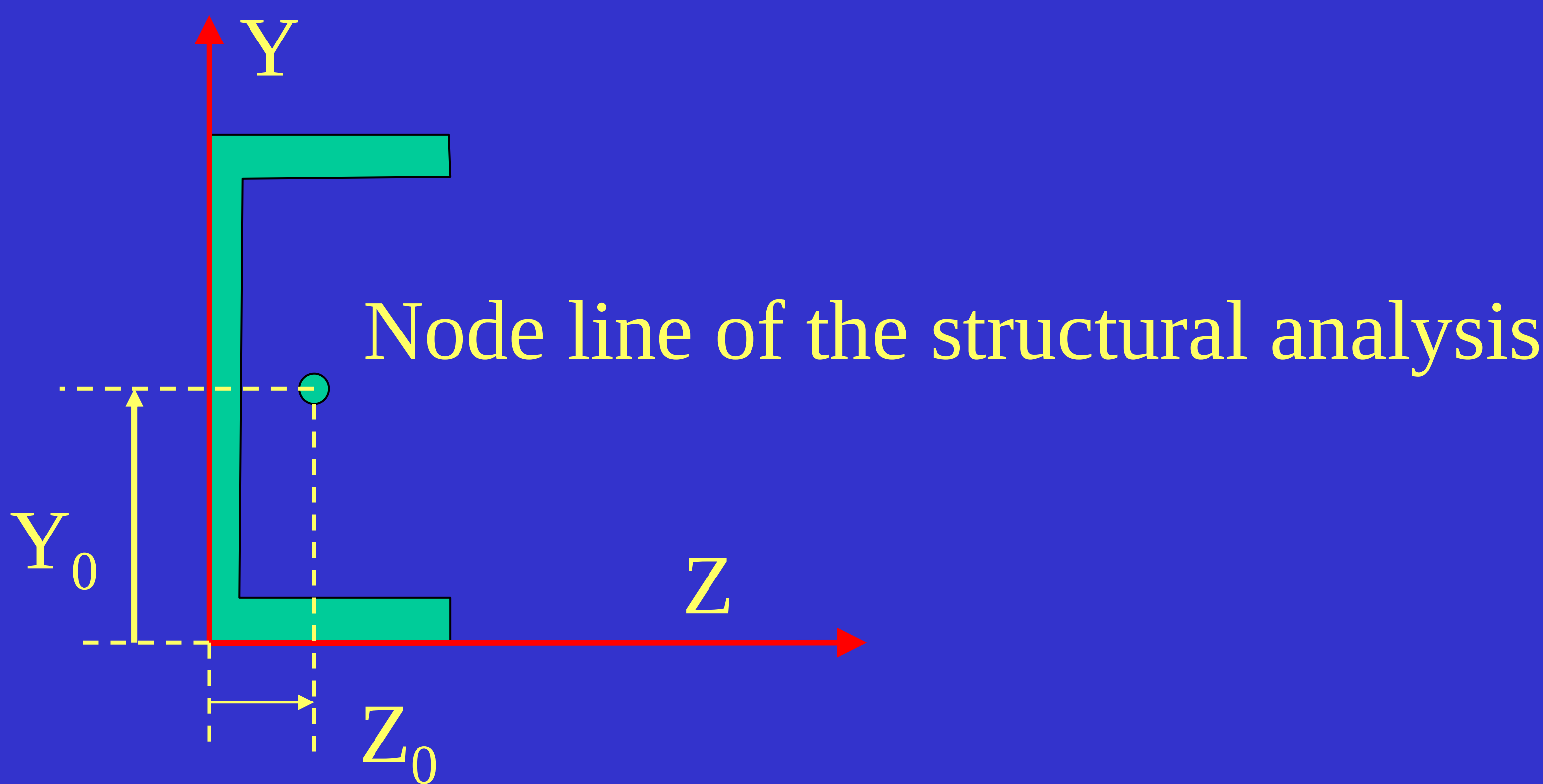
in the zones

and in the direction

of non linear temperature gradients.

Structure of the input file for thermal analyses

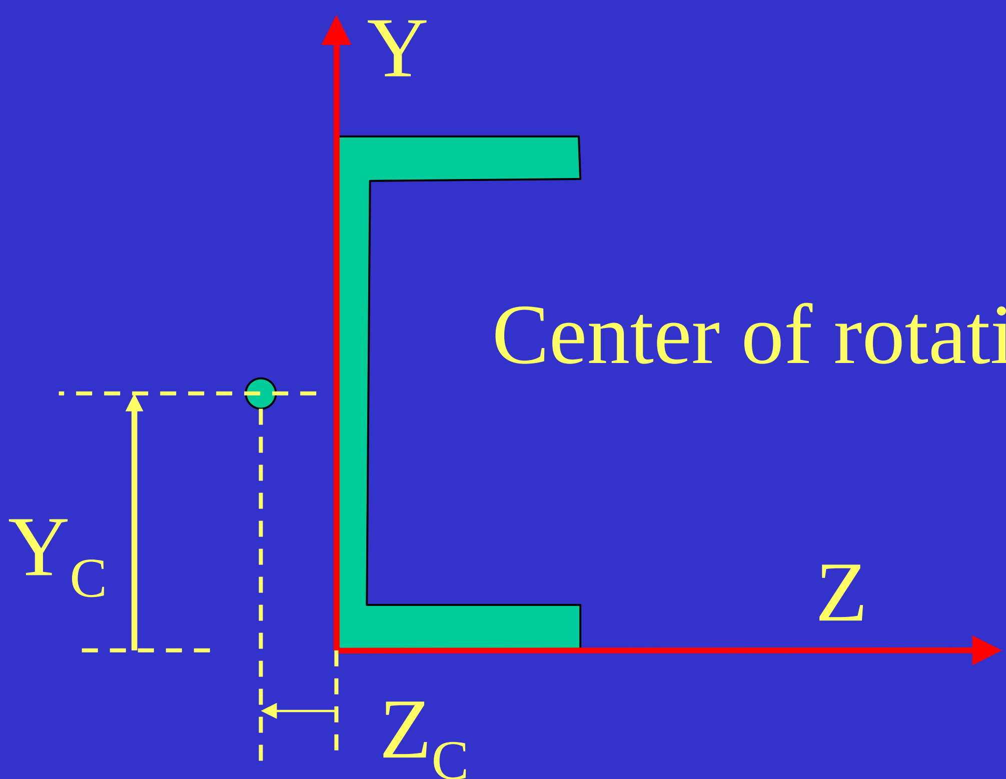
NODELINE	Y_0	Z_0
YC_ZC	Y_c	Z_c



Structure of the input file for thermal analyses

NODELINE Y_0 Z_0

YC_ZC Y_c Z_c

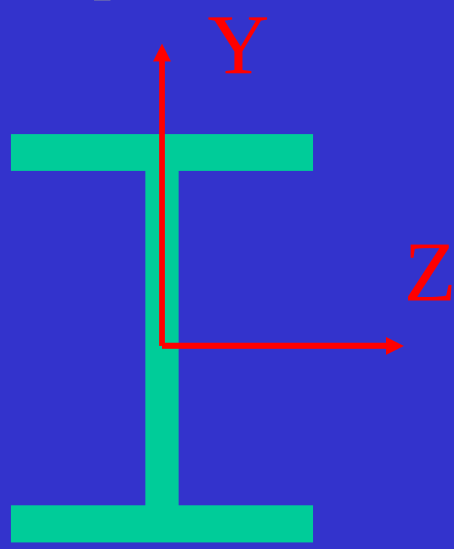


Center of rotation (structural analysis)

Symmetries

YSYM:

- ✓ The axis Y is an axis of symmetry (for the geometry of the section and for the boundary conditions).
- ✓ In order to decrease the size of calculation, we model only ½ of the section.
- ✓ The section of each represented "fiber" is doubled in the .TEM file.



$A_i \Rightarrow 2\ A_i$

! Valid only for 2D structural analyses

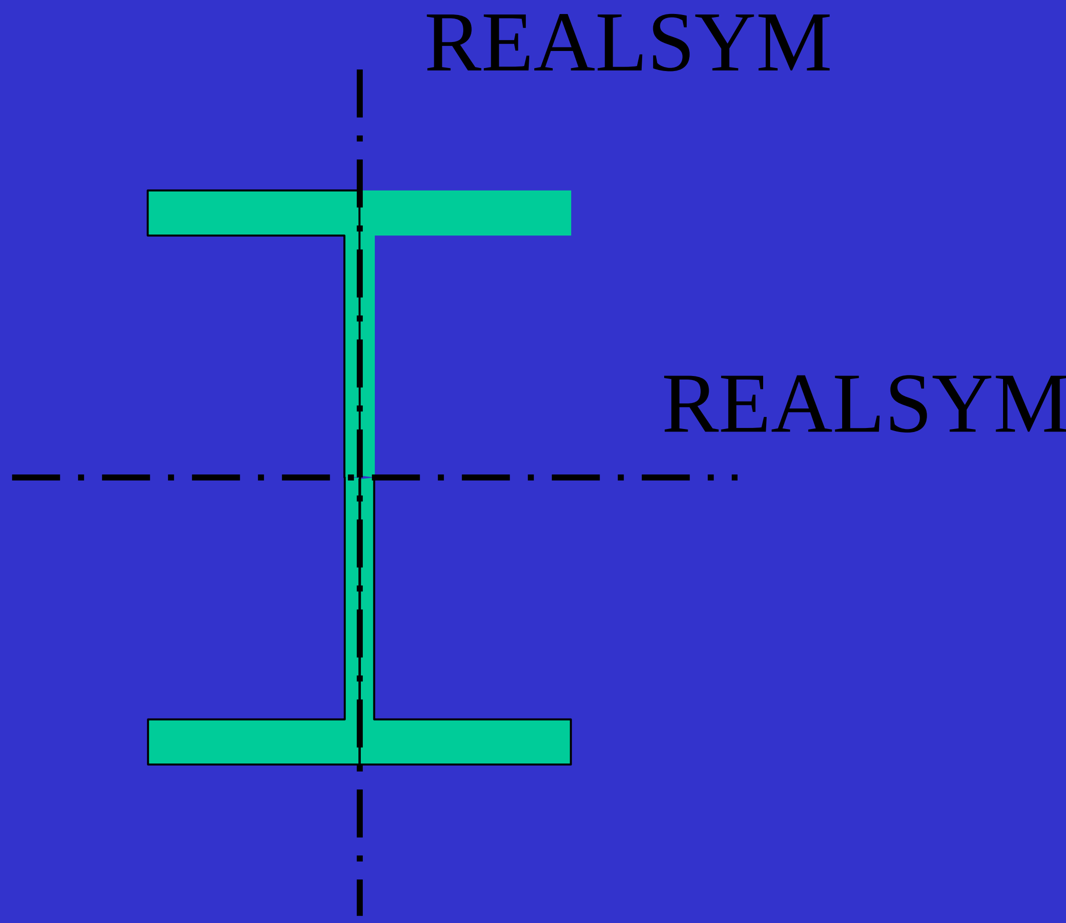
Symmetries

REALSYM:

- ✓ There is an axis of symmetry (for the geometry of the section and for the boundary conditions).
- ✓ In order to decrease the size of calculation, we model only ½ of the section.
- ✓ The section of each represented "fiber" is reproduced on the other side of the axis.

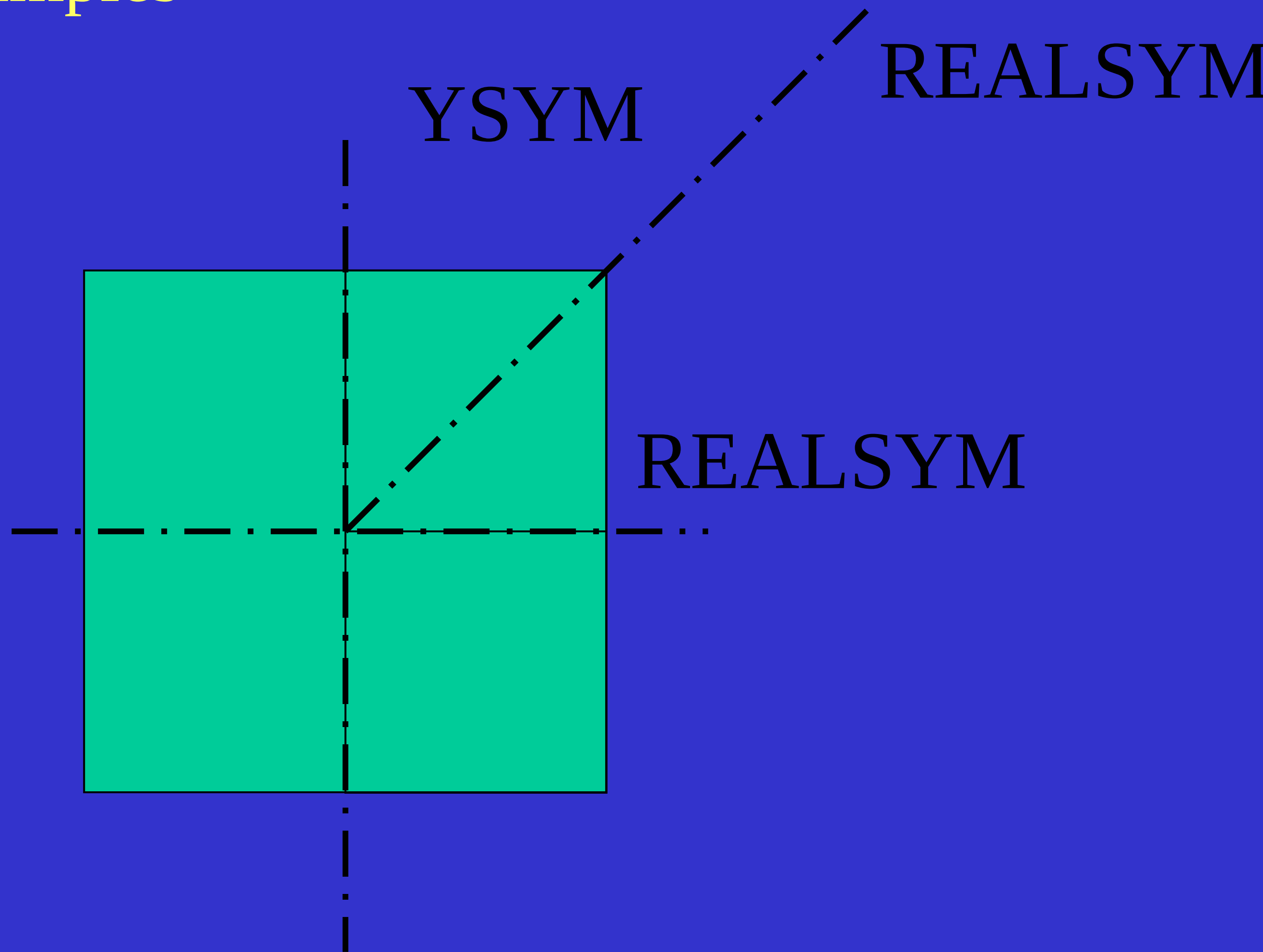
Symmetries

REALSYM: examples



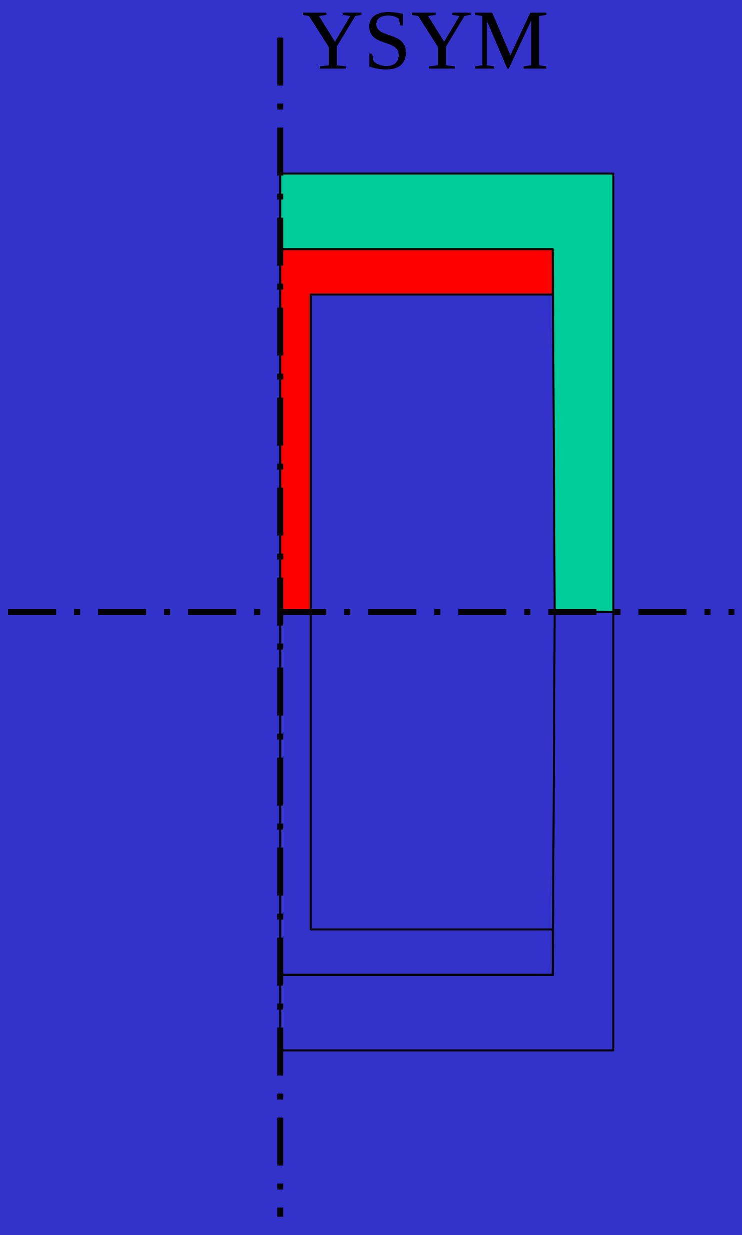
Symmetries

REALSYM: examples



Symmetries

SYMVOID



REALSYM
&
SYMVOID
(for calculation of the view factors in the cavity)