Overview of the development of fire engineering in research and practice

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Various methods for determining the fire resistance.

1. Experimental Tests
2. Tabulated data
3. Simple calculation models
4. Advanced calculation models

Method 1 : Experimental testing

➢ **Testing specimens for material behaviour**

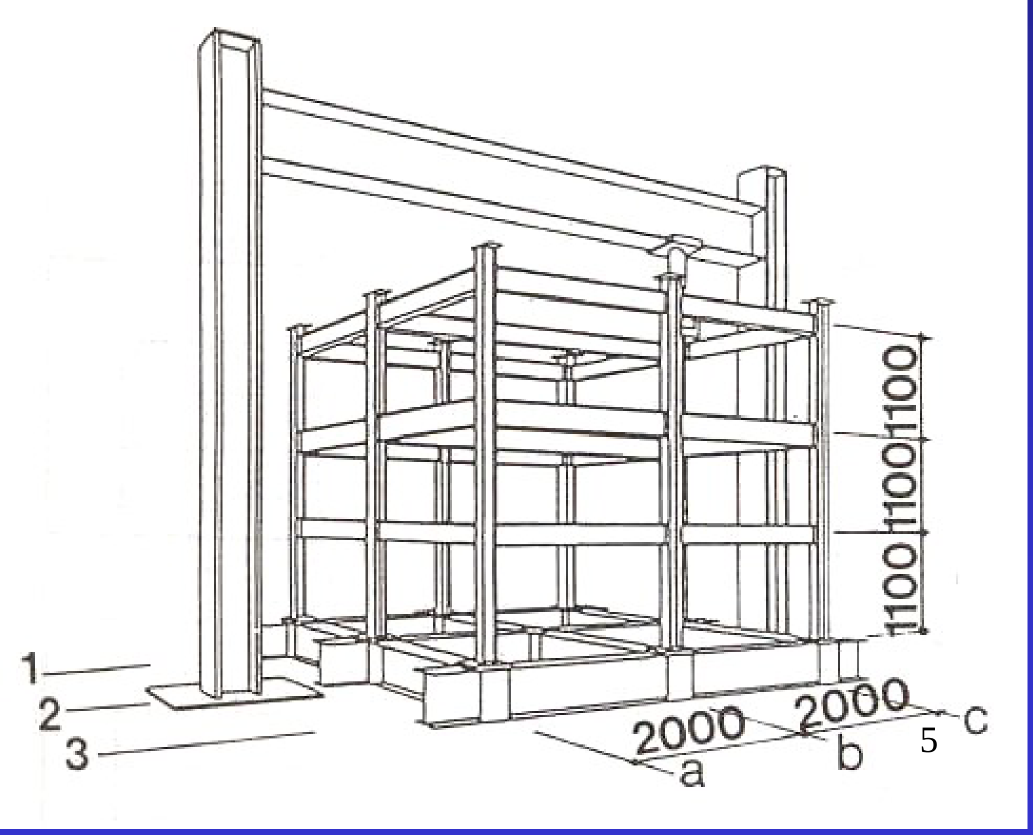
Method 1 : Experimental testing

- Testing material behaviour
- Standard fire tests.
  - Circumstancial disadvantages: cost, delays, limited # of facilities.
  - Real disadvantages: only elements, size of the element, boundary conditions, variability.

Method 1 : Experimental testing

- Testing material behaviour
- Standard fire tests
- Small scale fire tests

Steel: OK
Hydral materials: ???



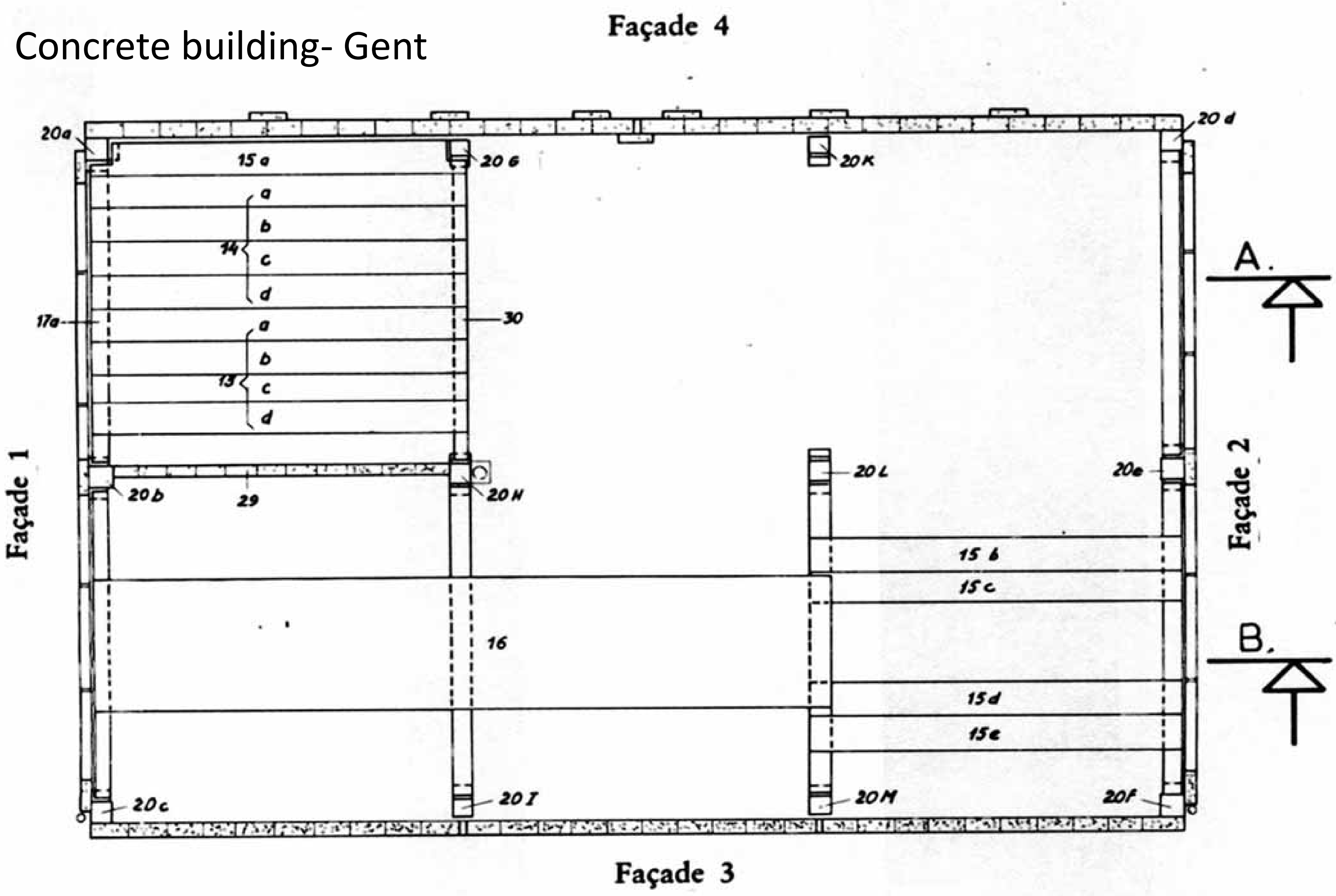
Picture from Nakamura et al.,
1rst IAFSS, Gaithersburg, 1985

Method 1 : Experimental testing

- Testing material behaviour
- Standard fire tests
- Small scale fire tests
- Large scale fire tests

Rare - Local fires - Observations more than research

Concrete building- Gent



⇒Experimental testing is used mainly in research.

⇒Experimental testing will remain forever.

- Verification of basic hypotheses used in calculation models
- Integrity criteria in separating elements

Method 2 : Tabulated data

Definition: presentation, in simple form, of results obtained by other methods.

Standard fire resistance	Minimum dimensions (mm)			
	Slab thickness h_s	Axis-distance *a*		
		One way	Two way	
			$l_y/l_x \leq 1.5$	$1.5 < l_y/l_x \leq 2$
1	2	3	4	5
REI 30	60	10*	10*	10*
REI 60	80	20	10*	15*
REI 90	100	30	15*	20
REI 120	120	40	20	25
REI 180	150	55	30	40
REI 240	175	65	40	50

l_y and l_x are the spans of a two-way slab where l_y is the longer span.
For prestressed slabs the increase of axis distance should be noted.
The axis distance *a* in Column 4 and 5 for two way slabs relate to slabs supported on all four edges. Otherwise, they should be treated as one-way spanning slabs.
* Normally the cover required at room temperature will control

Method 2 : Tabulated data

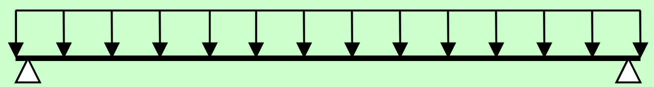
Reinforcement ratio ω = 0.50 ; Eccentricity **e** ≤ 200 mm					
Standard fire resistance	λ	Column width b_{min} / axis distance *a*			
		n = 0.15	*n* = 0.30	*n* = 0.50	*n* = 0.70
R30	30	150/25*	150/25*	250/35:300/25*	500/40:550/25*
	40	150/25*	150/30:200/25*	300/35:450/25*	550/30
	50	150/25*	200/30:250/25*	400/40:500/25*	550/50:600/40
	60	150/25*	200/35:300/25*	450/50:550/25*	(1)
	70	150/25*	250/40:400/25*	500/40:600/30*	(1)
	80	150/25*	300/40:500/25*	550/50:600/40*	(1)
R 60	30	150/30:200/25*	200:40:450/25*	450/50:550/30	550/50:600/40
	40	150/35:250/25*	250:40:500/25*	500/40:550/35	600/60
	50	200/35:300/25*	300:45:550/25*	500/55:550:40	(1)
	60	200/40:500/25*	400:40:600/30	550/50:600/45	(1)
	70	200/40:550/25*	500:40:550/35	600/60	(1)
	80	250/40:600/25*	500:40:600/35	(1)	(1)
R 90	30	250/40:450/25*	300/50:500/25	500/55:600/40	600/80
	40	200/50:500/25*	350/50:550/35	550/60:600/50	(1)
	50	250/45:550/25*	500/45:550/40	600/60	(1)
	60	250/50:550/30	500/50:550/45	600/80	(1)
	70	300/50:550/35	550/50:600/45	(1)	(1)
	80	350/50:600/35	550/60:600/50	(1)	(1)
* Normally the cover at room conditions will control (1) Requires a width greater than 600 mm.					

Method 3 : Simple calculation models

Definition: Method based on global equilibrium conditions.

$$M_{\max} \leq R_d$$

$$\frac{q\,L^2}{8} \leq W_{pl}\, f_y$$

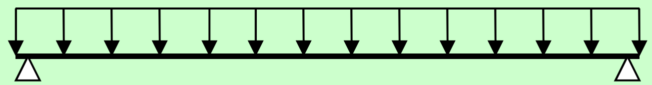


Method 3 : Simple calculation models

- **Extrapolations of similar methods used at room temperature**
- **Can be used « by hand »**
- **One method for each material/member type.**
- **Not well suited for complex structures.**

=> Used for real projects.

$$\text{At } 20°C : \quad \frac{q_d\, L^2}{8} \leq W_{pl}\, f_y$$



$$\text{At high temperature} : \quad \frac{q_{d,fi}\, L^2}{8} \leq W_{pl}\, f_y(T)$$

Method 4 : Advanced calculation models

Definition: Based on principles of structural mechanics or of heat transfer (local equations).

$$\frac{\partial \sigma_{xx}}{\partial x} + \frac{\partial \sigma_{xy}}{\partial y} + \frac{\partial \sigma_{xz}}{\partial z} + F_x = 0$$

$$\frac{\partial \sigma_{yx}}{\partial x} + \frac{\partial \sigma_{yy}}{\partial y} + \frac{\partial \sigma_{yz}}{\partial z} + F_y = 0$$

$$\frac{\partial \sigma_{zx}}{\partial x} + \frac{\partial \sigma_{zy}}{\partial y} + \frac{\partial \sigma_{zz}}{\partial z} + F_z = 0$$

$$\lambda\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right) + Q - c\rho\frac{\partial T}{\partial t} = 0$$

Method 4 : Advanced calculation models

- **Finite differences, finite elements, boundary elements.**

- **Require a computer (numerical calculation models).**

Three different families of software:

1. '*My Ph.D.*' software
    - One author (university)

Three different families of software:

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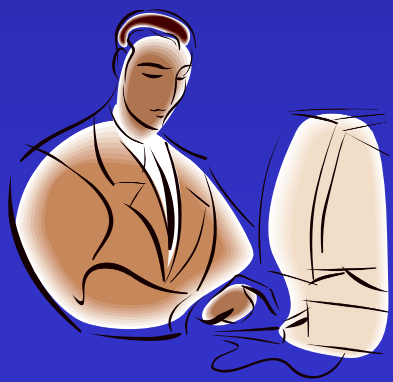
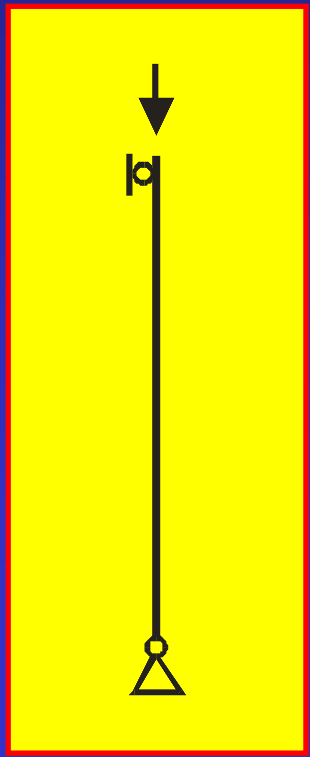
   - Limited field of application





Three different families of software:

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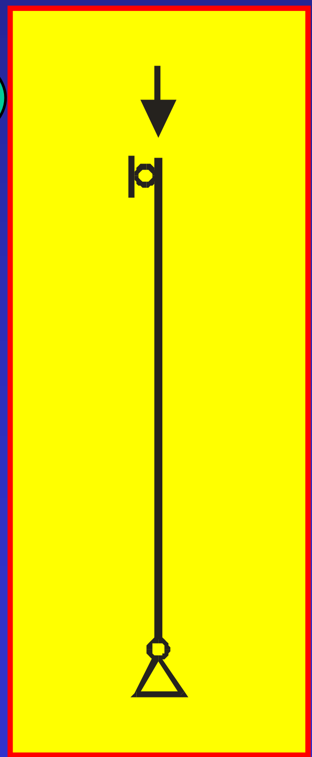
   - Limited availability



Three different families of software:

1. '*My Ph.D.*' software
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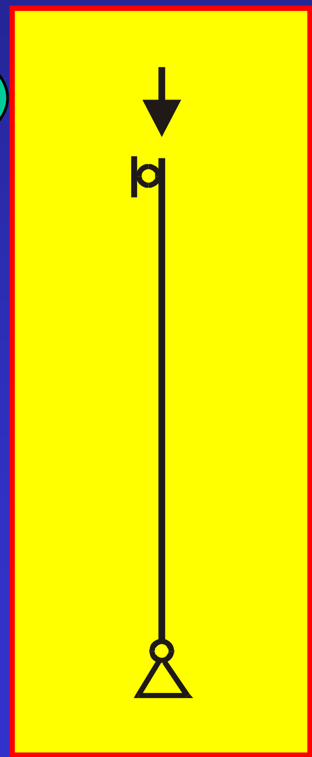
   - Limited field of application
   - Limited availability
   - Limited durability



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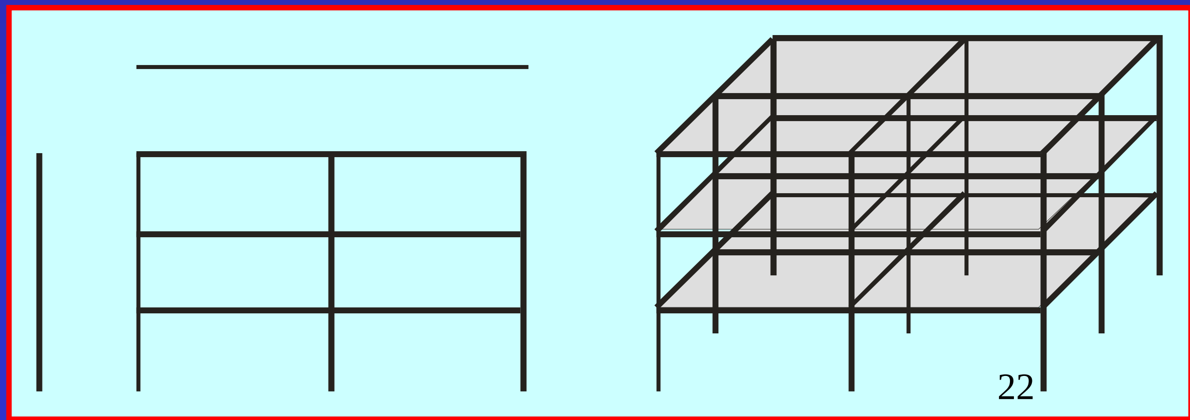
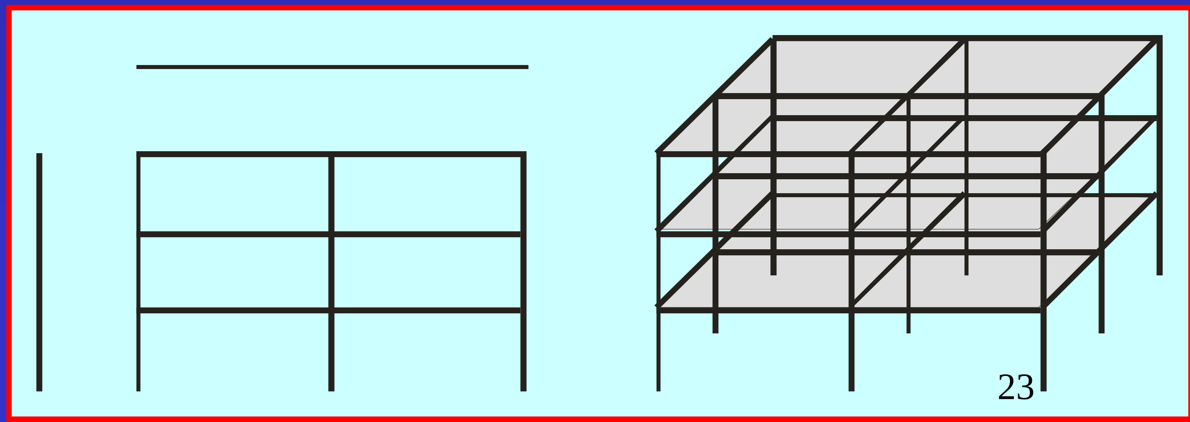
   - From a group (University)
   - Wider field of application



Three different families of software:

1. '*My Ph.D.*' software
2. Dedicated software (VULCAN, SAFIR,…)
   - From a group (University)
   - Wider field of application
   - Become available now



Three different families of software:

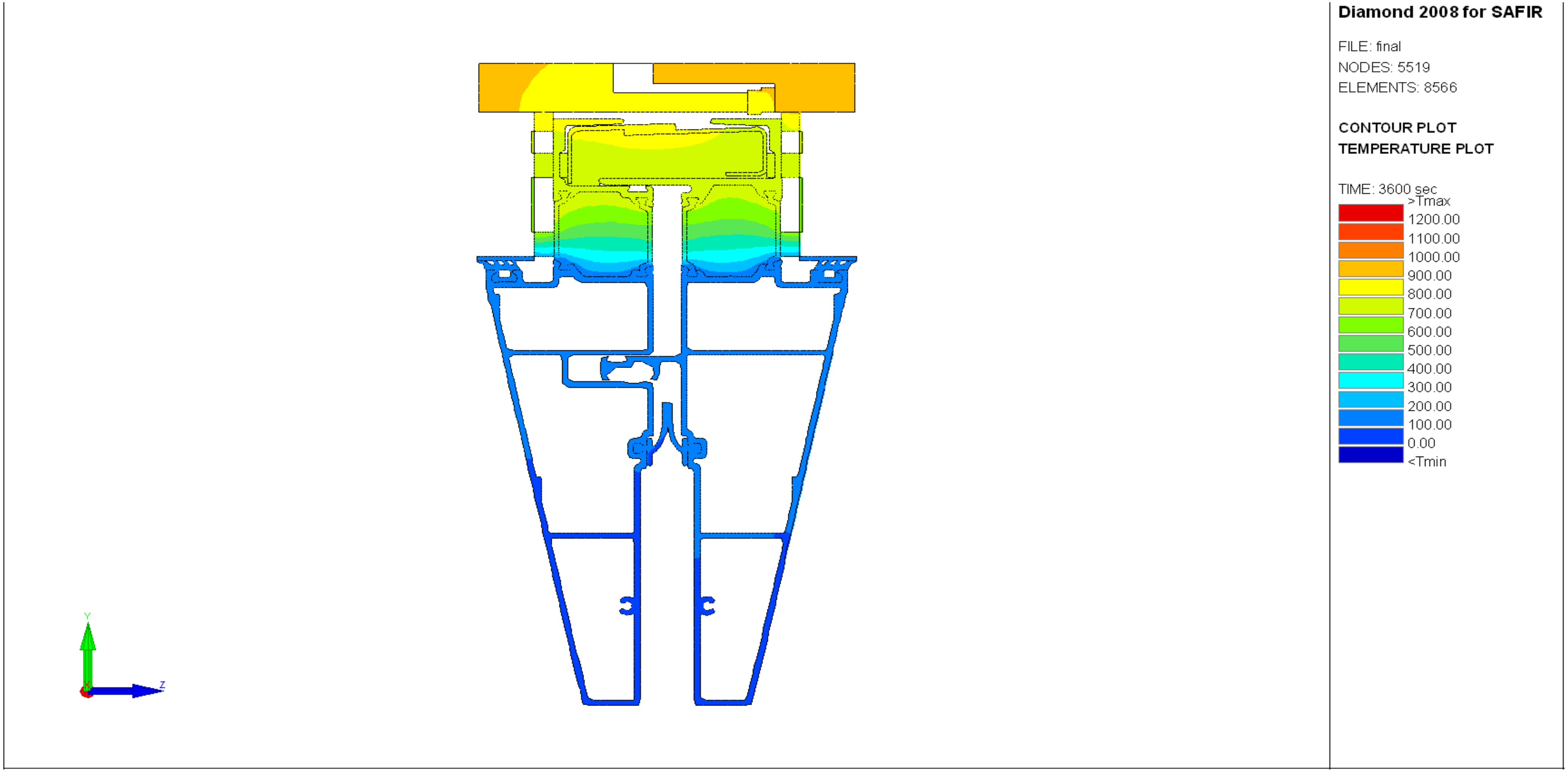
1. '*My Ph.D.*' software
2. Dedicated software (VULCAN, SAFIR,…)
3. Commercial software (ANSYS, ABAQUS,…)
   - Widely distributed, used and validated
   - Price !!!
   - Nice graphics

+ + + or - - - ?

What can we model and what should we test?

Which material can we model?

- A priori, all of them…
- if we have the properties.
- Which properties?
  - Properties of the material?
  - No. Properties of the model.
  - => Know the limits of your model.



Window frame (courtesy: Permasteelisa)

What can we model and what should we test?

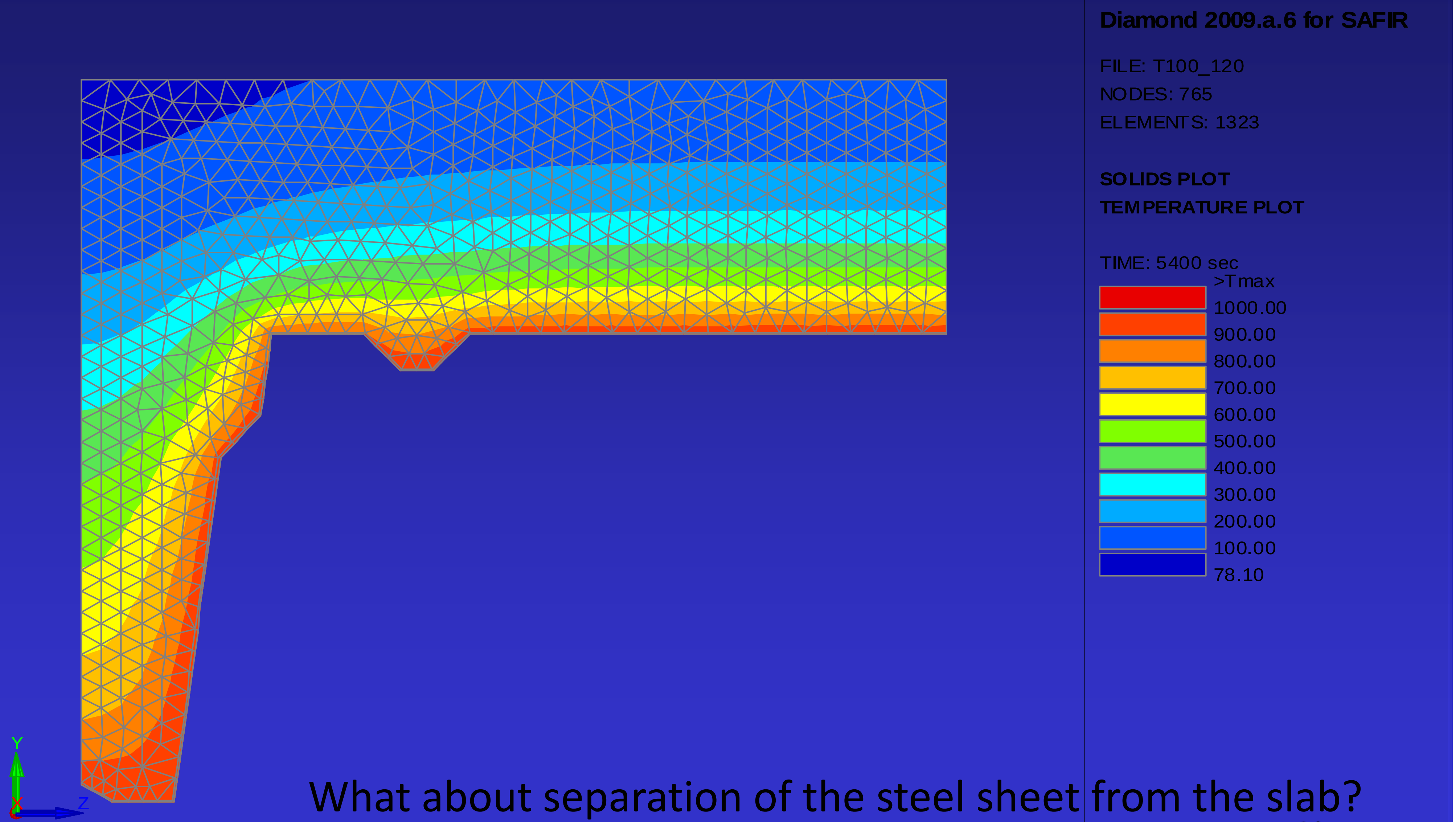
Which structure can we model?

A priori, none of them…

except if we made a test before on a similar structure.

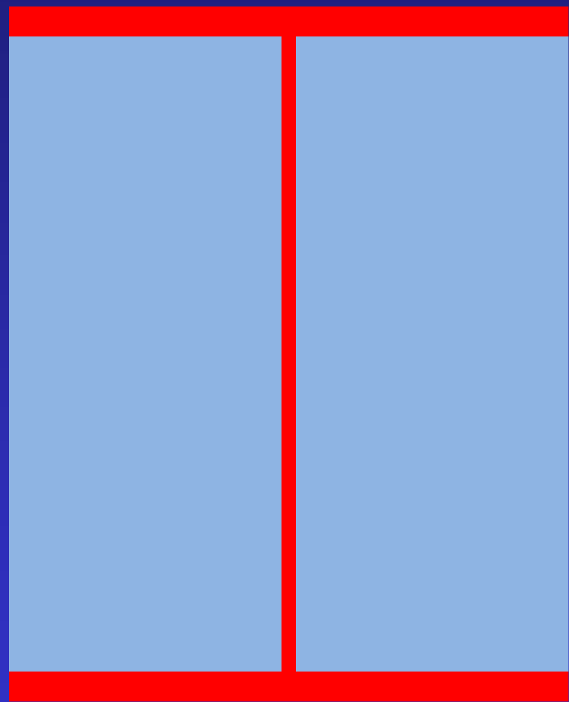
examples

1) Composite floor on corrugated steel sheets

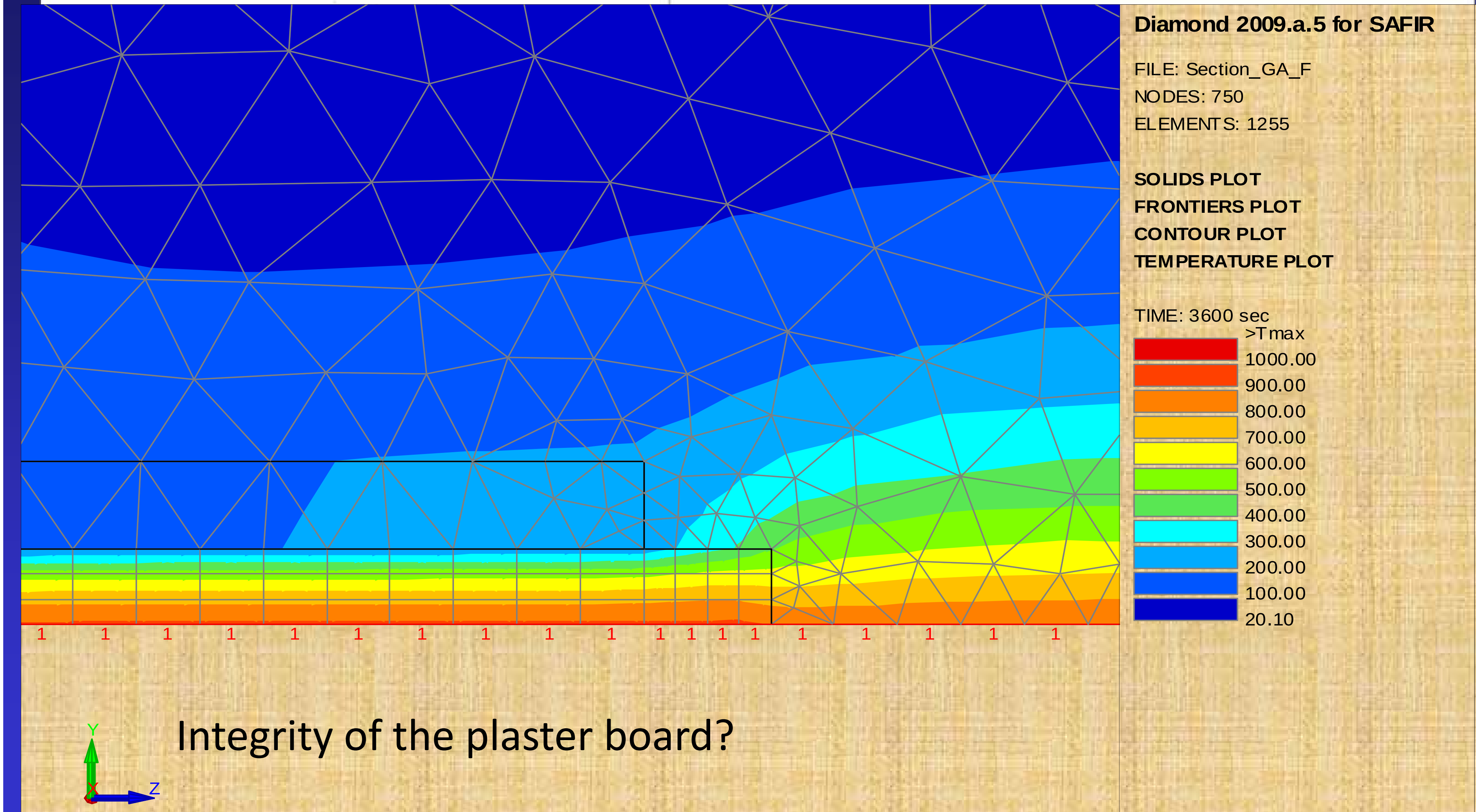


What about separation of the steel sheet from the slab?

2) Composite steel concrete columns



3) Steel plate covered by a plaster board

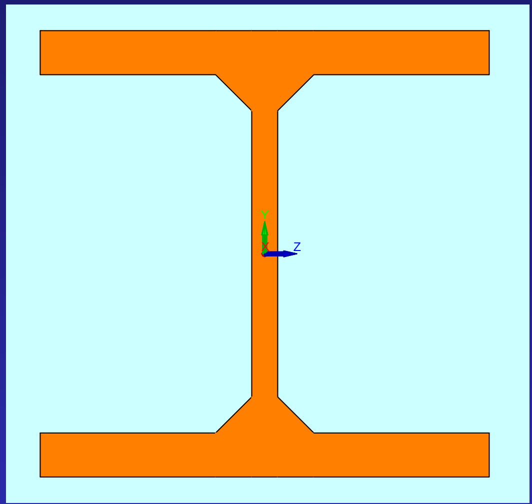


Integrity of the plaster board?

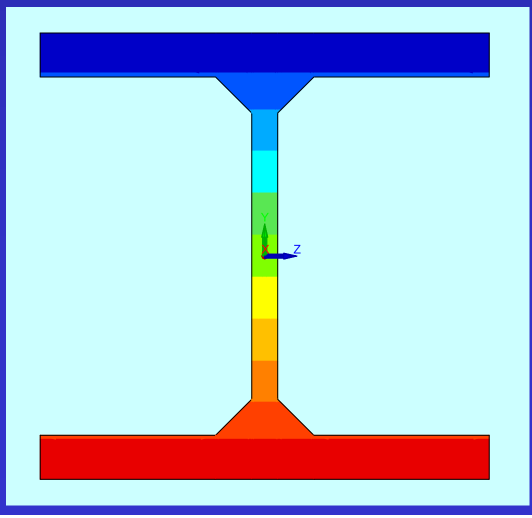
Method 4 : Advanced calculation models

Yesterday

Uniform temperature

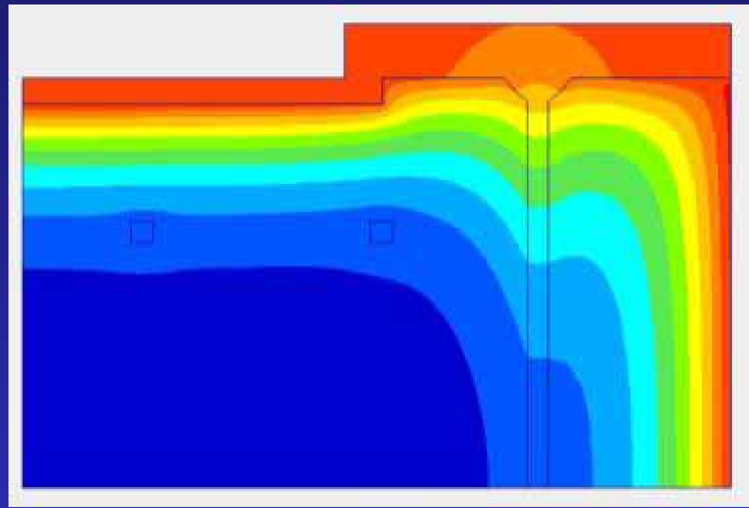


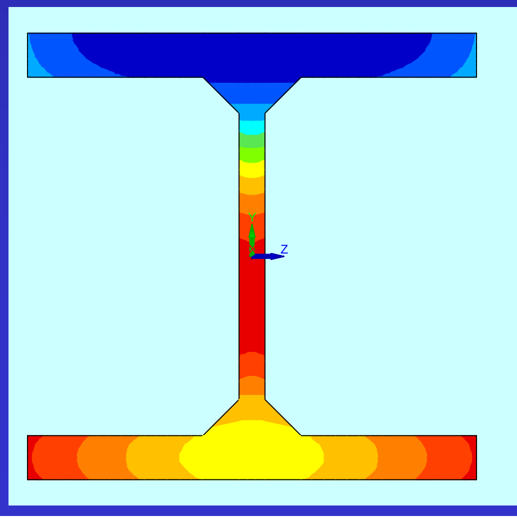
Linear gradient

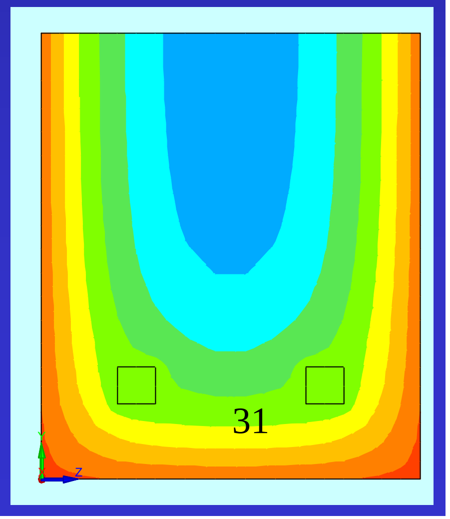


Today

Non uniform temperature







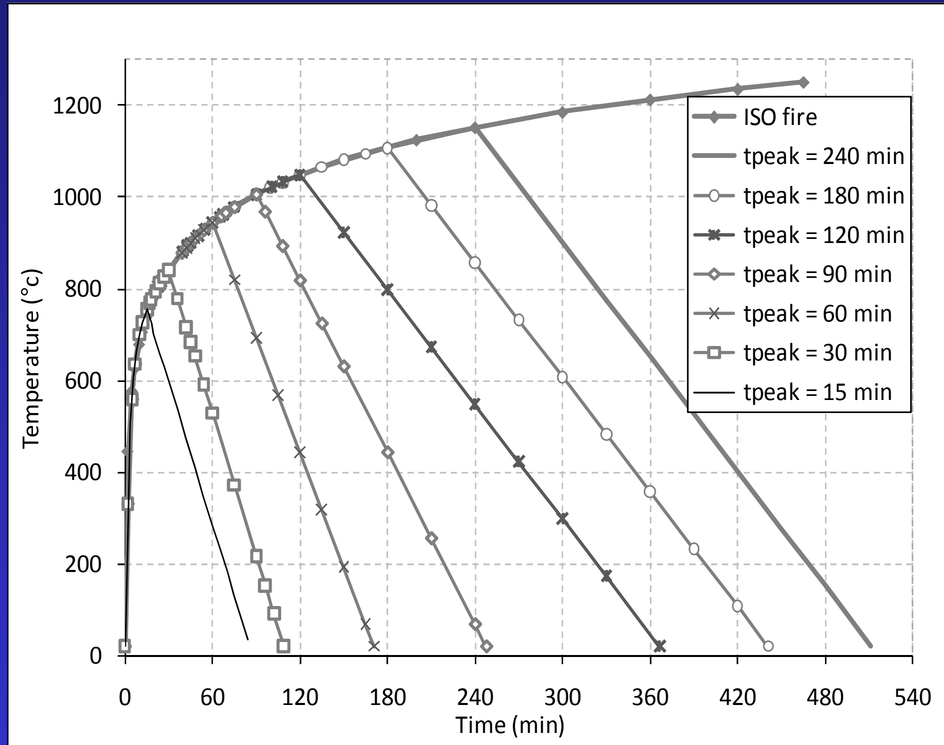
Method 4 : Advanced calculation models

Yesterday

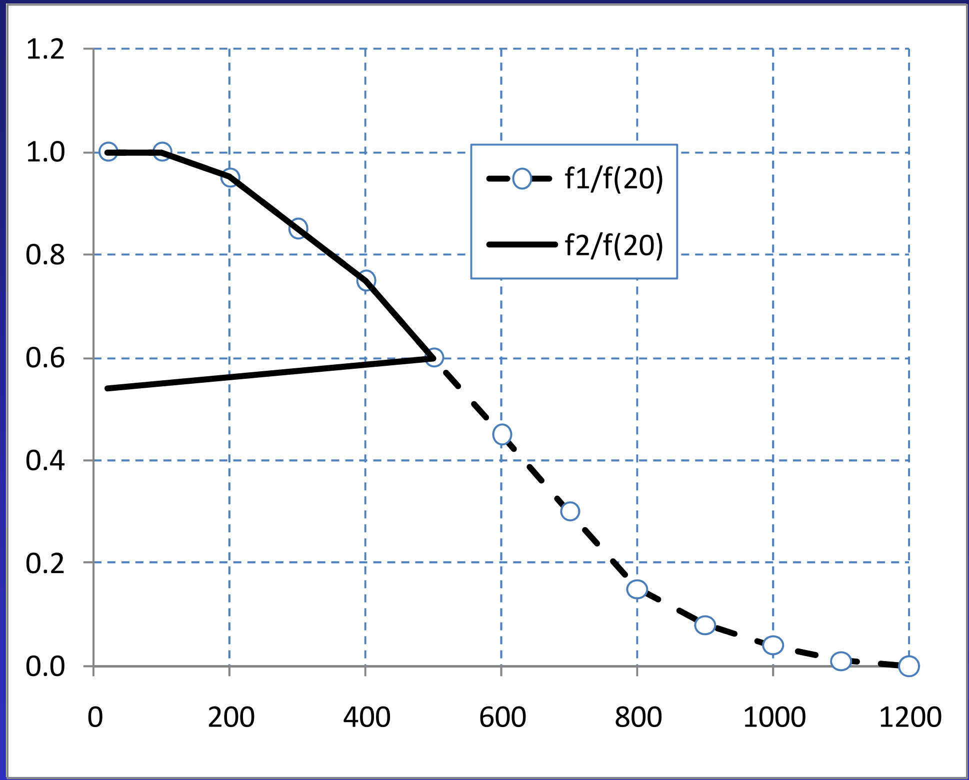
ISO fire

Today

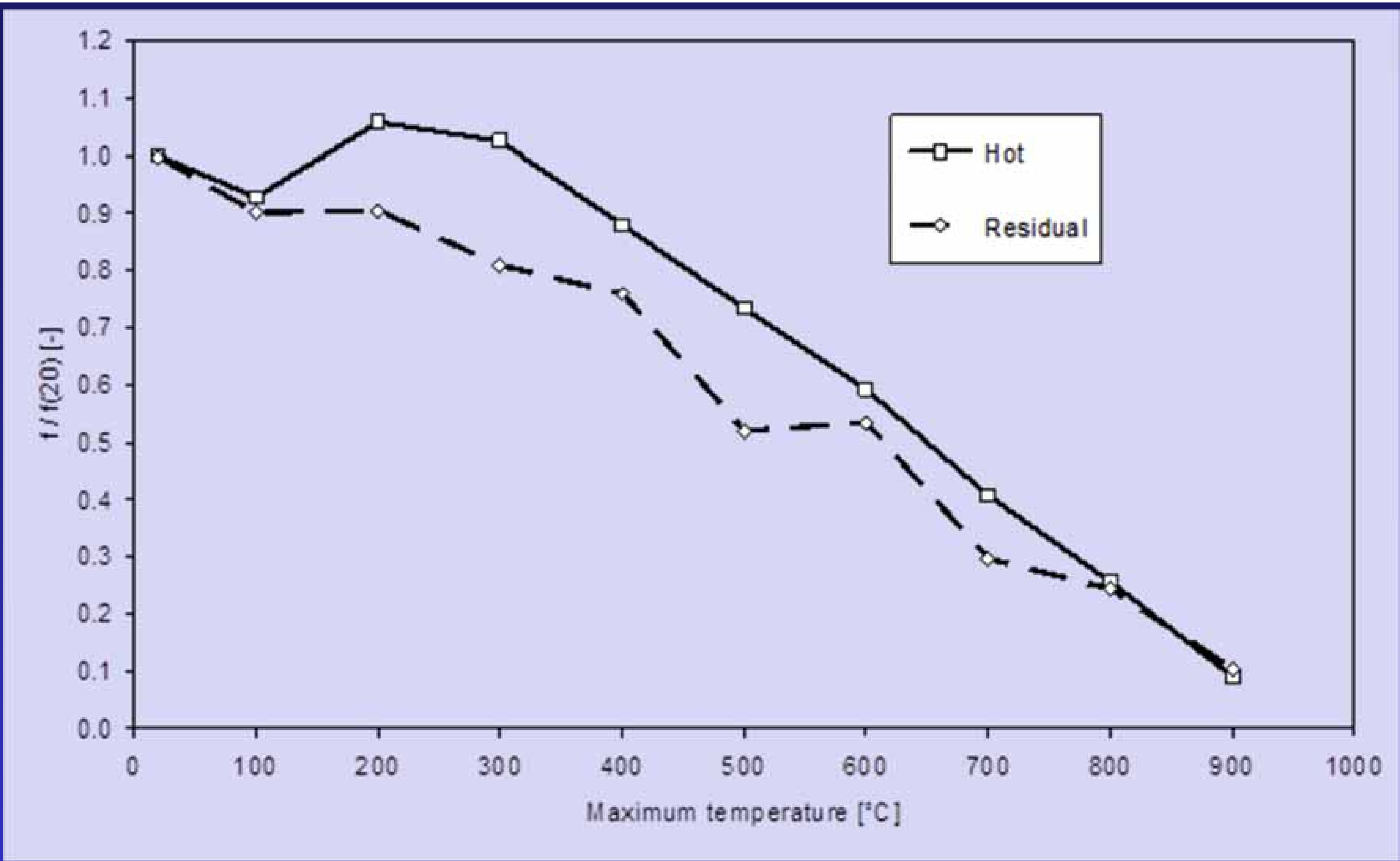
Natural fires (with cooling phase)



Requires specific material models.



Compressive strength of concrete



Difference between hot and residual compressive strength

From Li & Franssen, Journal of Structural Fire Engineering, 2(1), 2011, 29-44.

Collapse of an undergroud car park after the fire has been put down

Yesterday

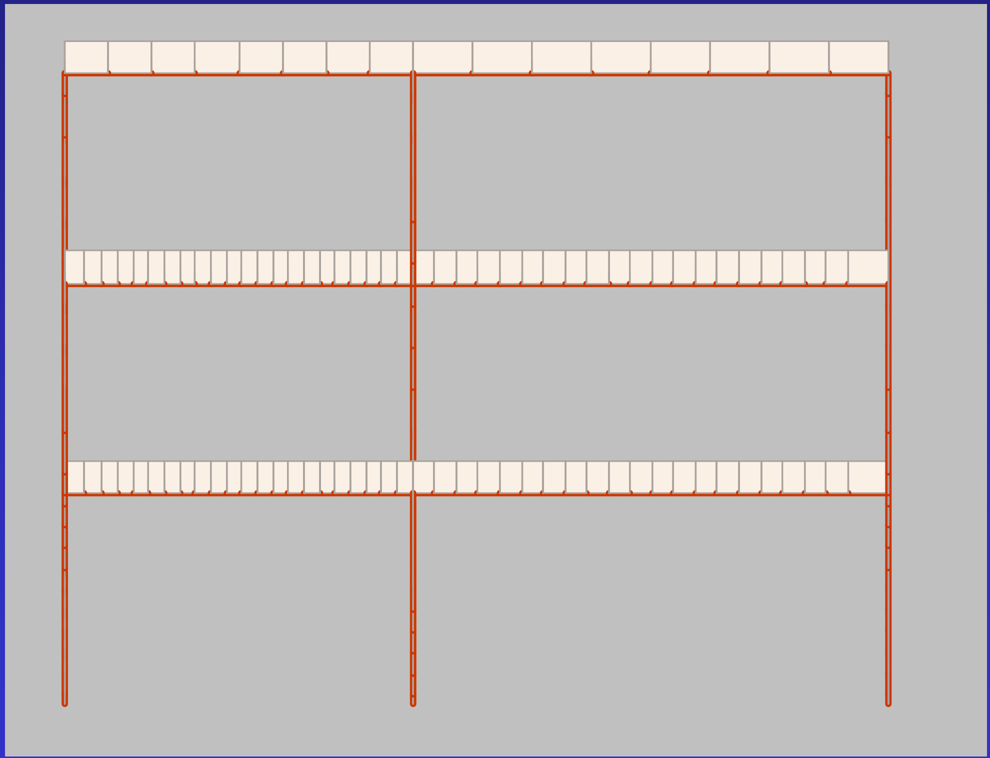
Implicit transient creep

Today

Explicit transient creep

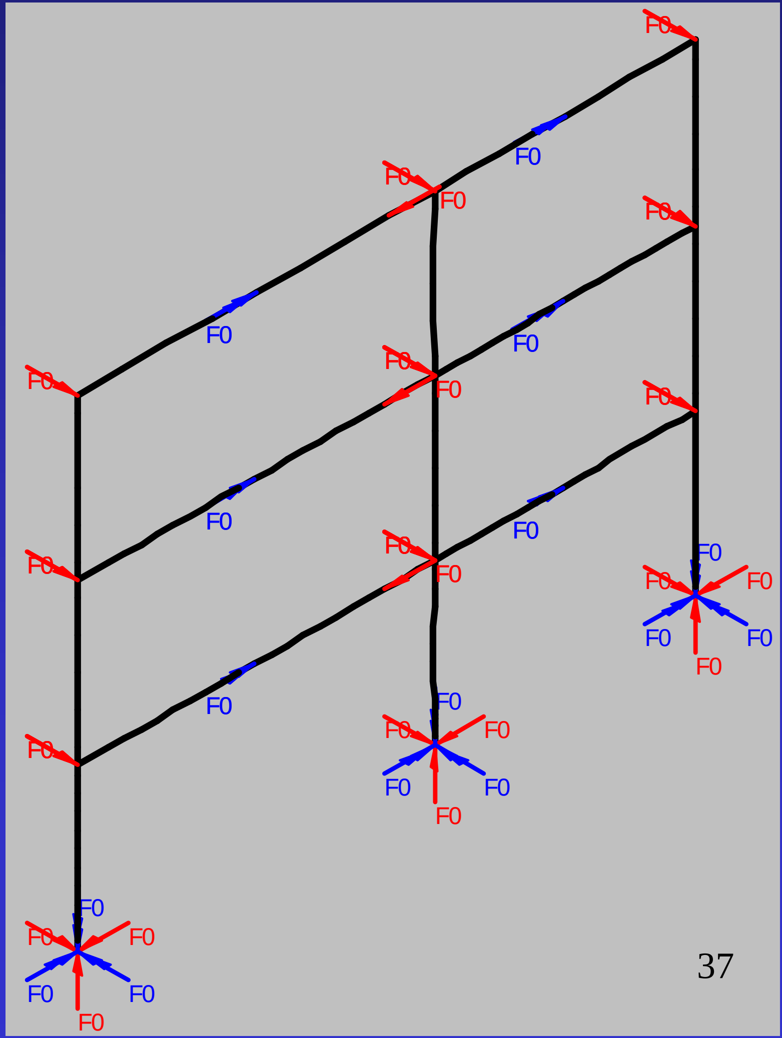
Yesterday

Single members or 2D frames



Today

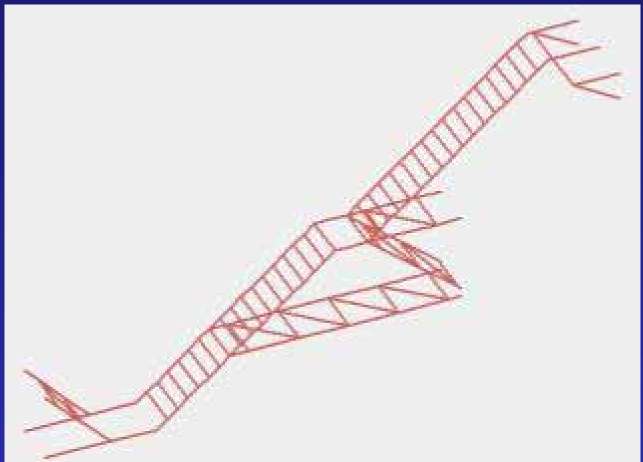
3D analyses

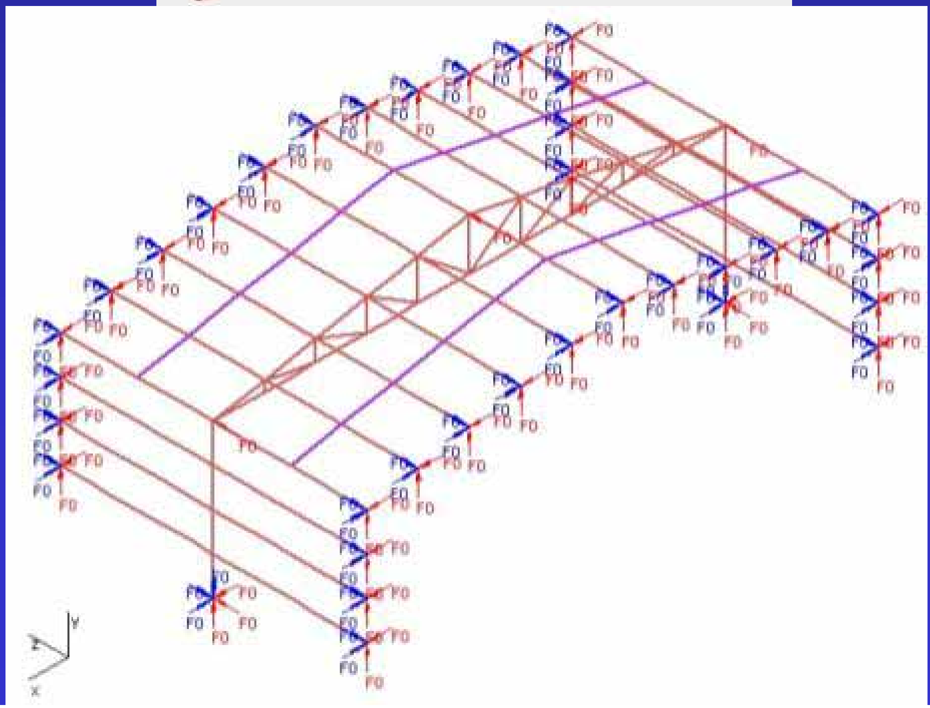


Method 4 : Advanced calculation models

Yesterday

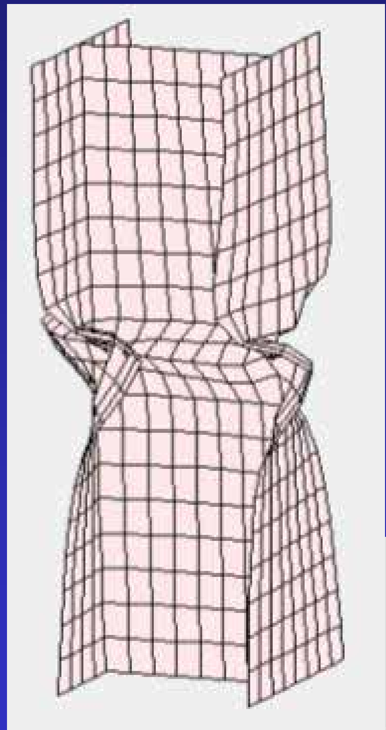
Linear elements

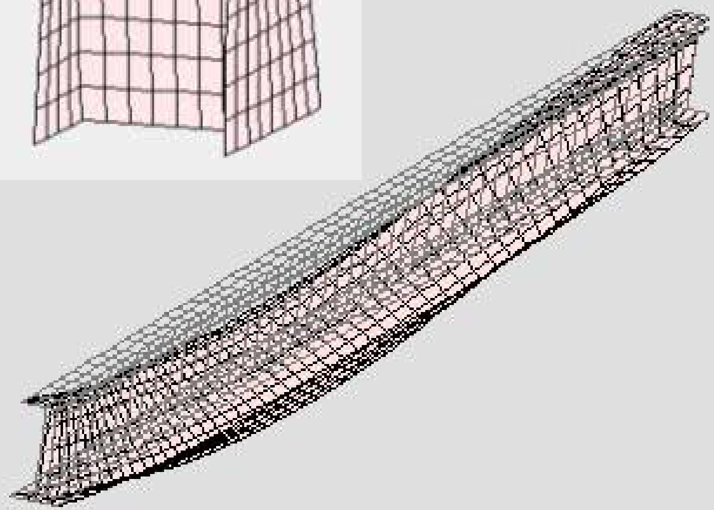


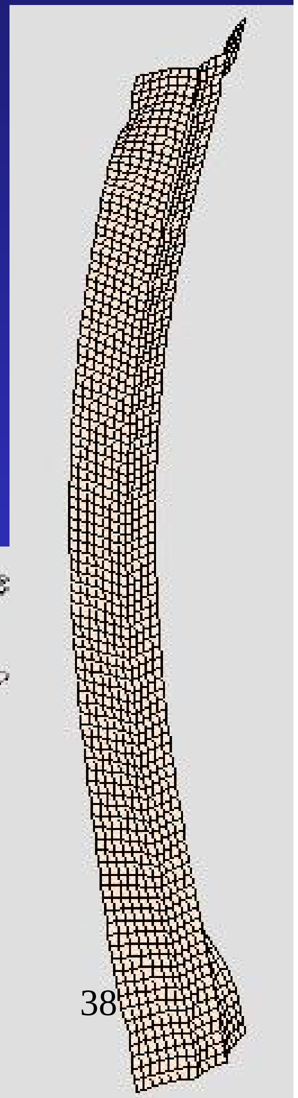


Today

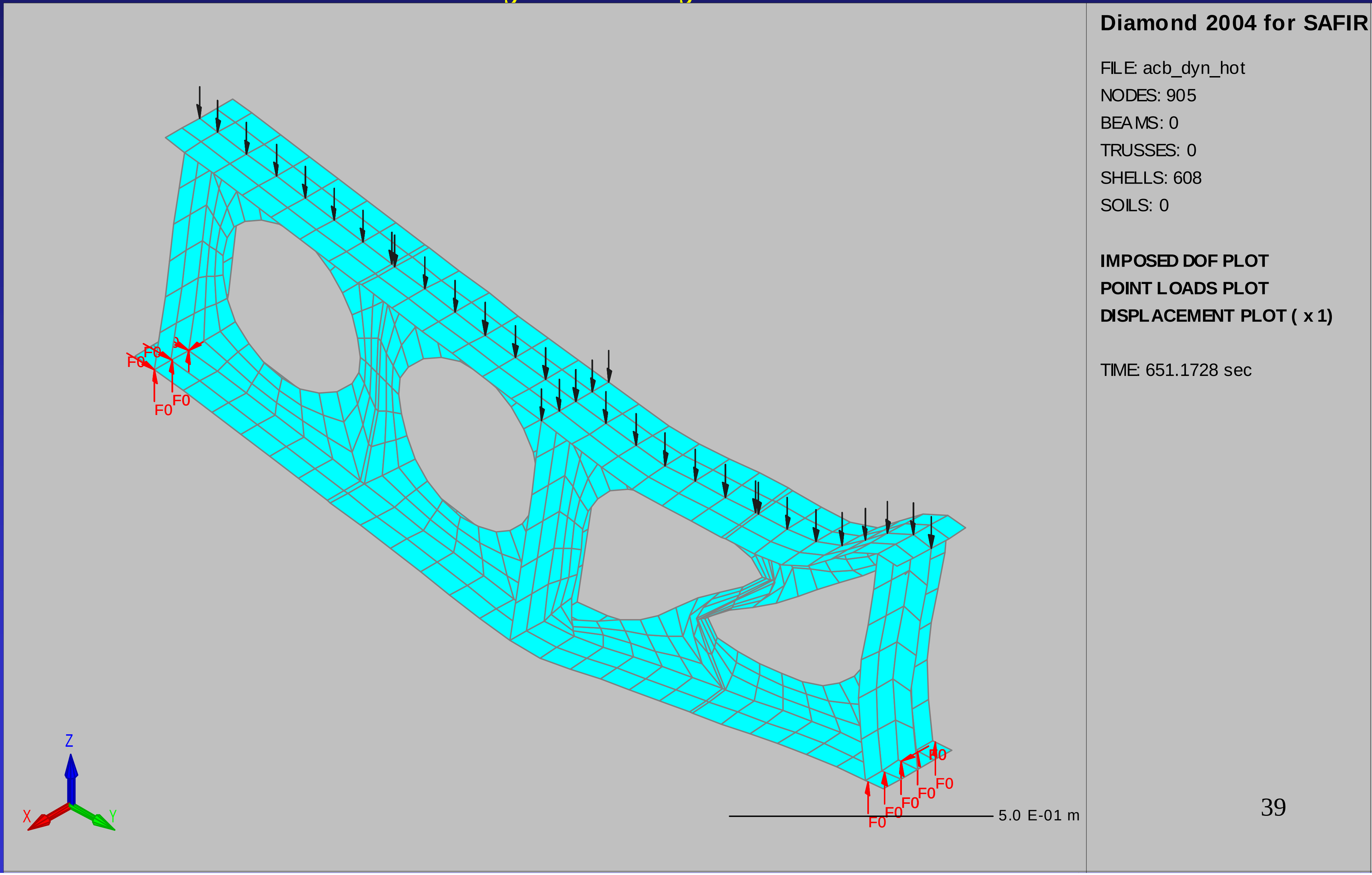
Shell elements



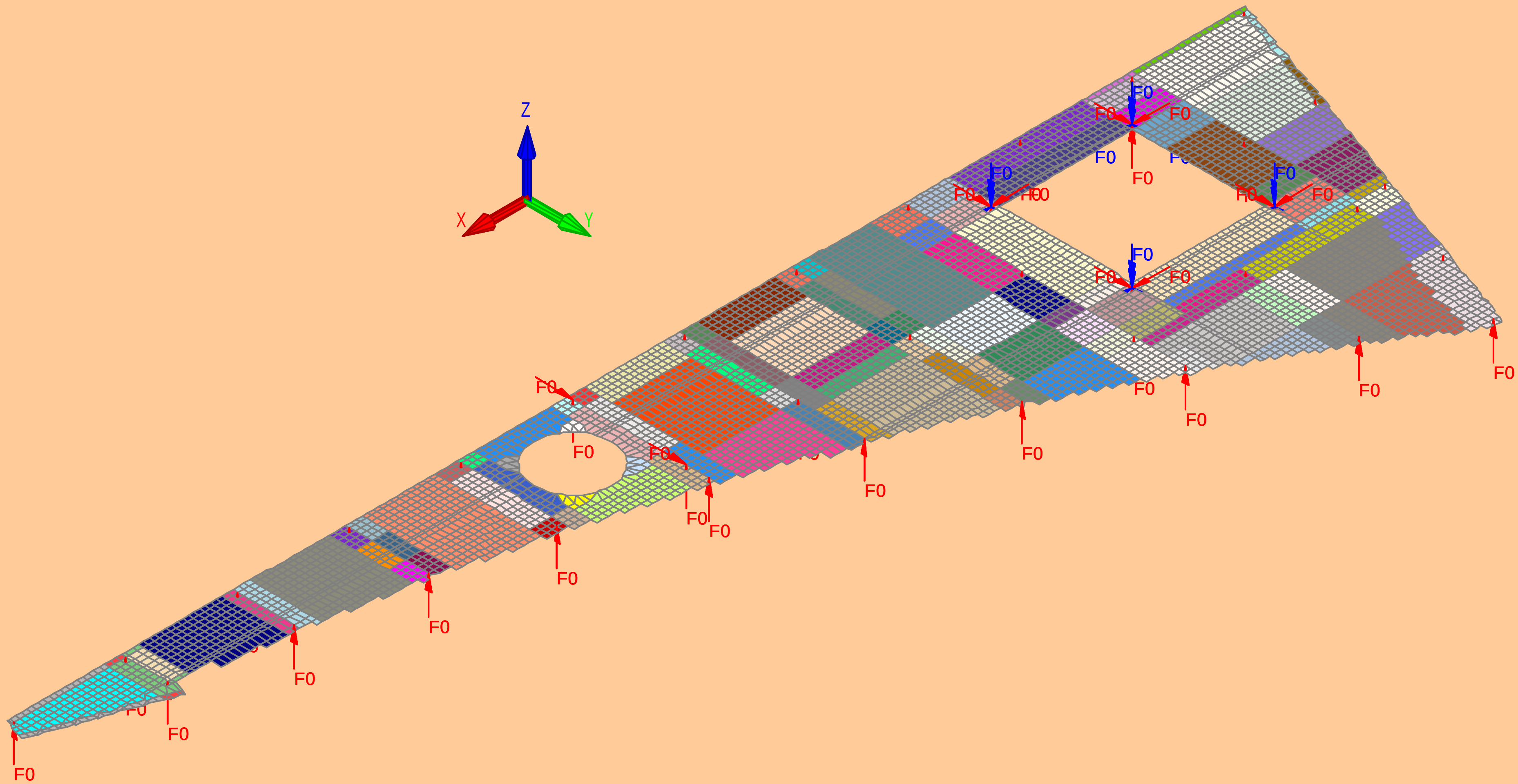




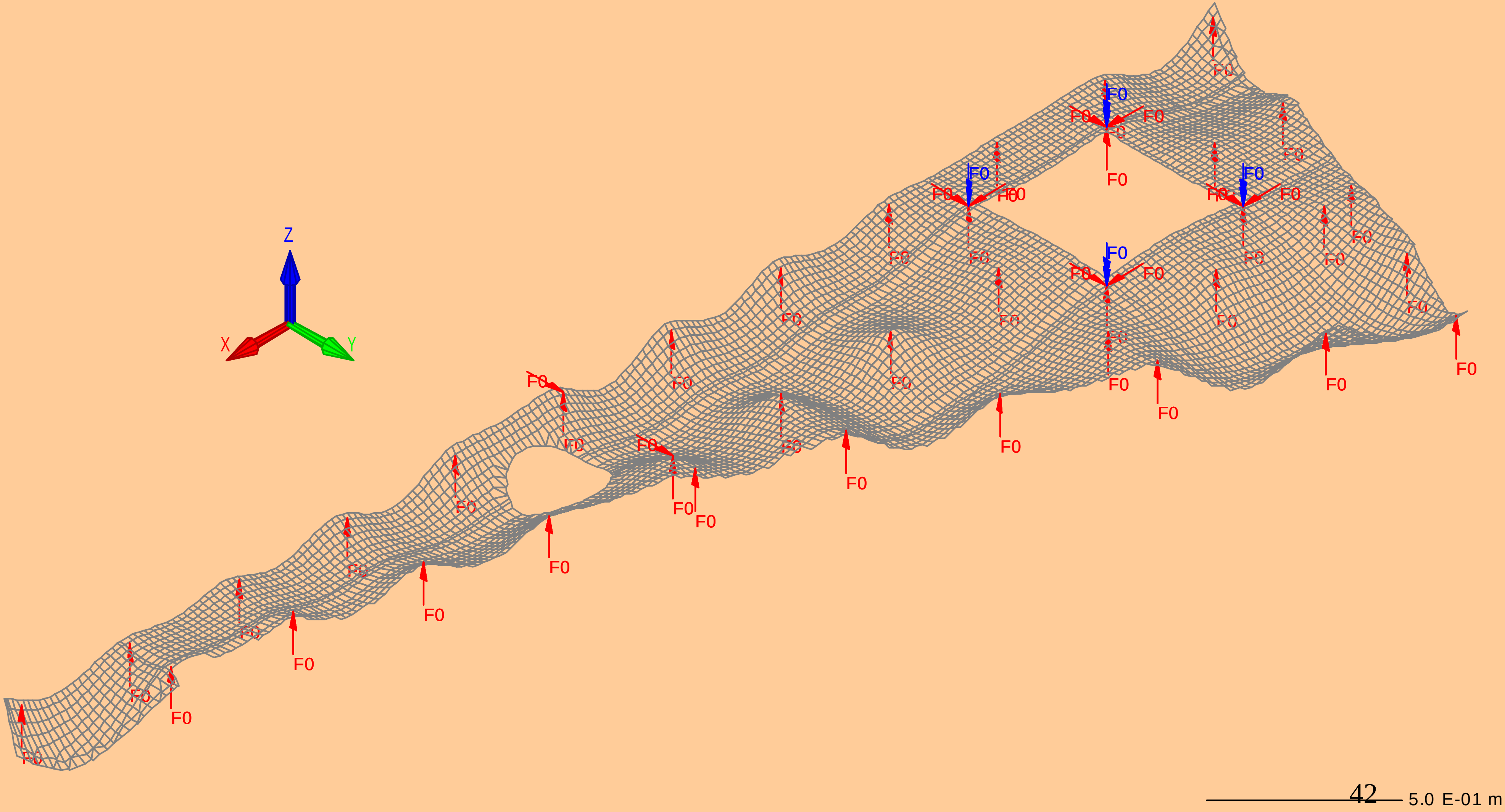
Short Cellular Steel beam
Symmetry not used



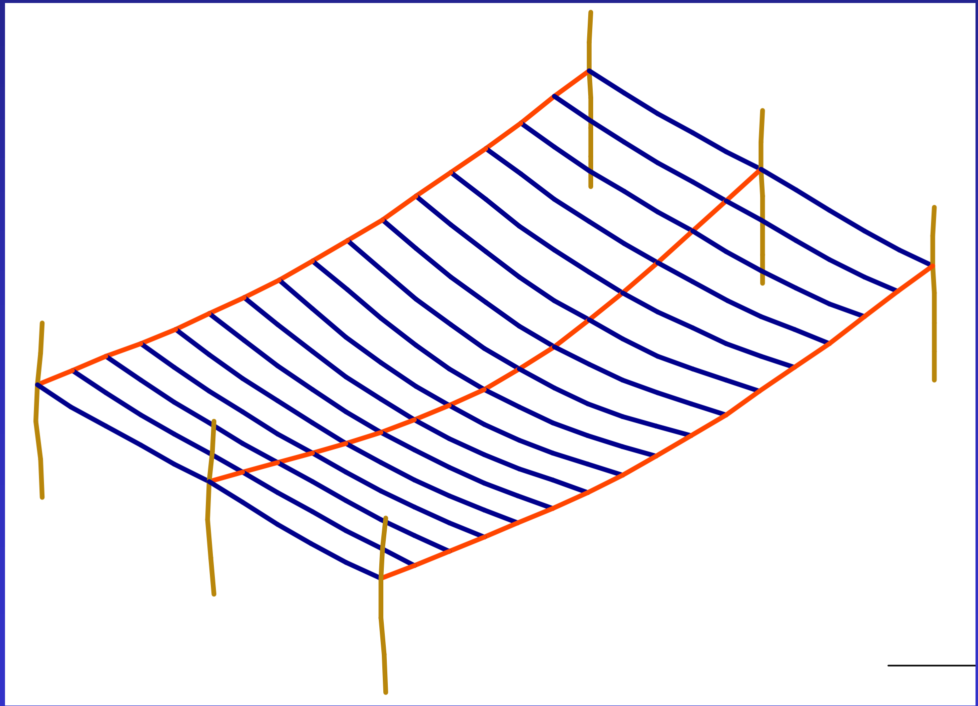

Reinforced concrete flat slab (20°C)
Courtesy "Batiserf, Grenoble"

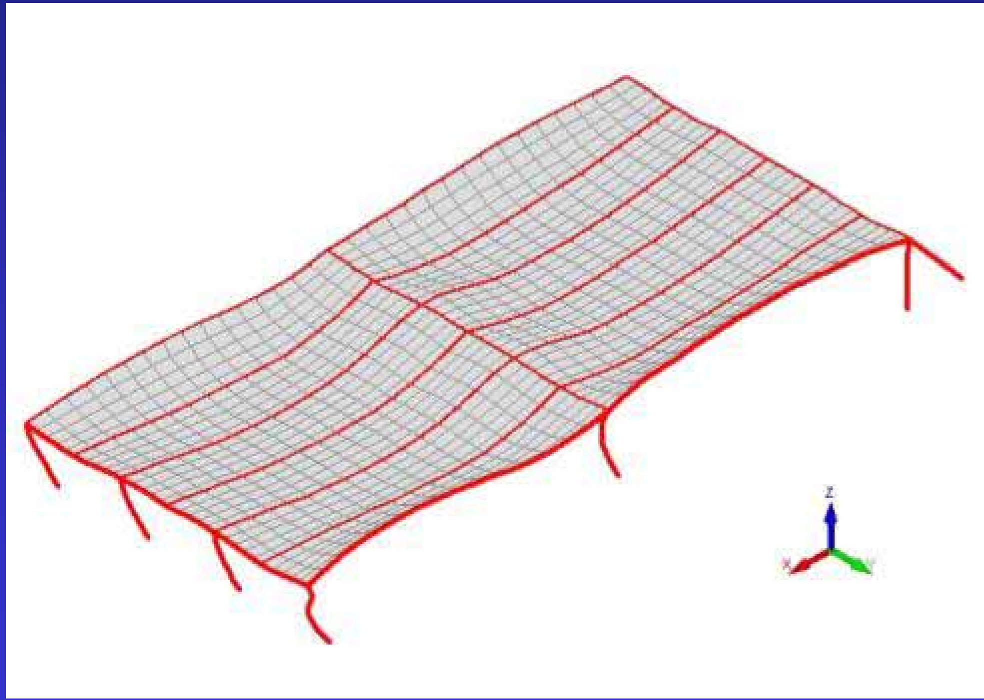

Z
X
Y

Displacement in the ultimate limit state



Yesterday	Today
One type of F.E.	Several types of F.E.



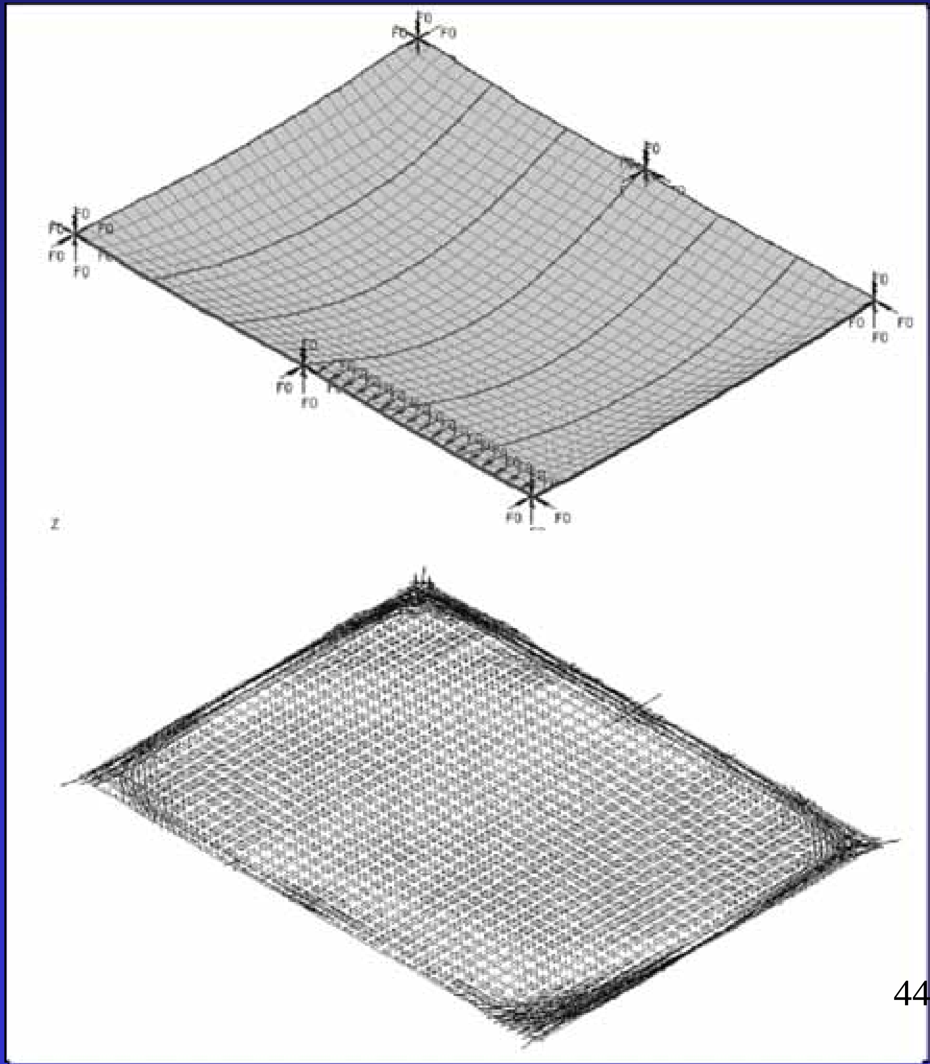


Yesterday

One way bending in floors

Today

Tensile membrane action



Yesterday

Static analyses

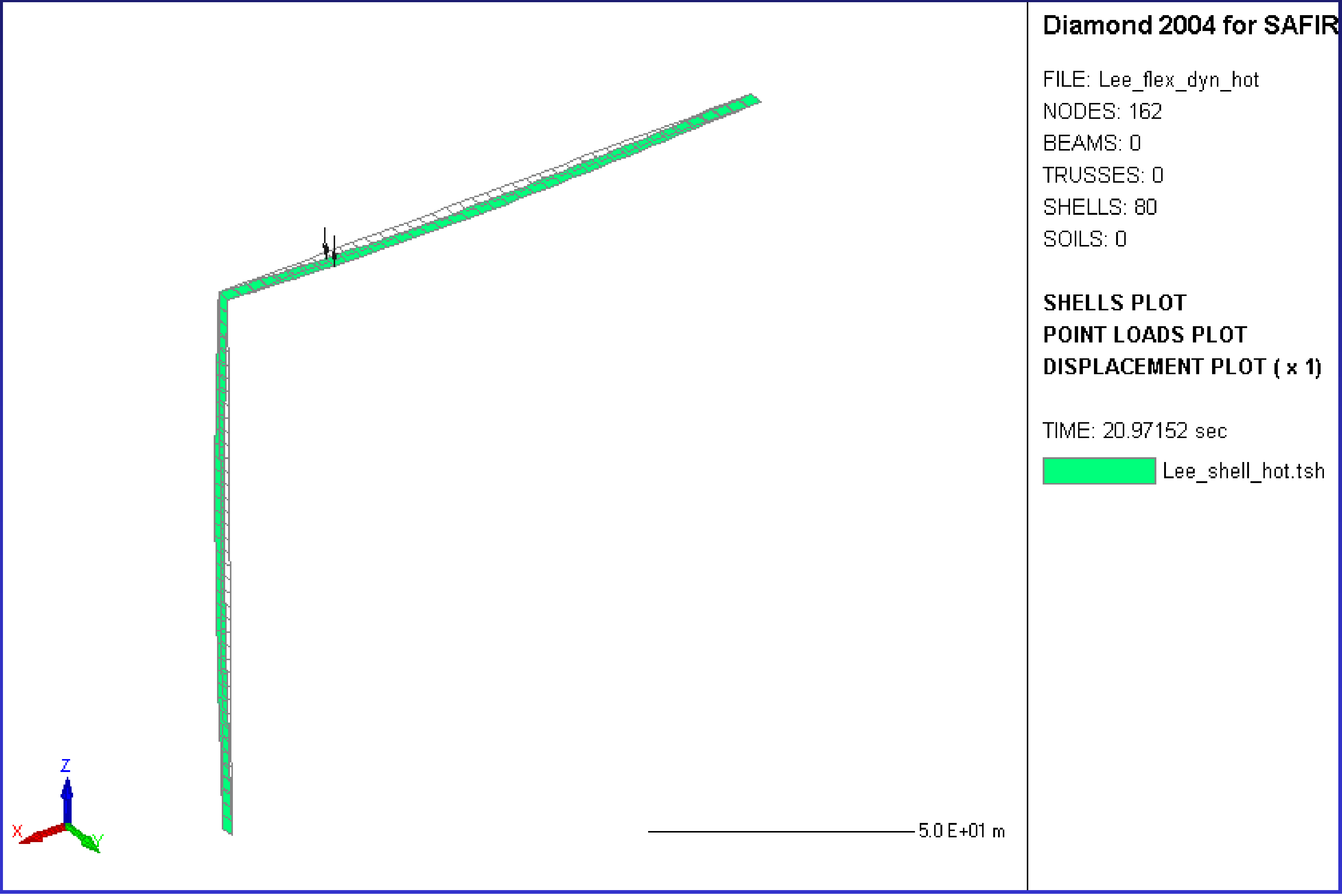
$$\{\Delta F\} = [K]\{\Delta u\}$$

Today

Dynamic analyses

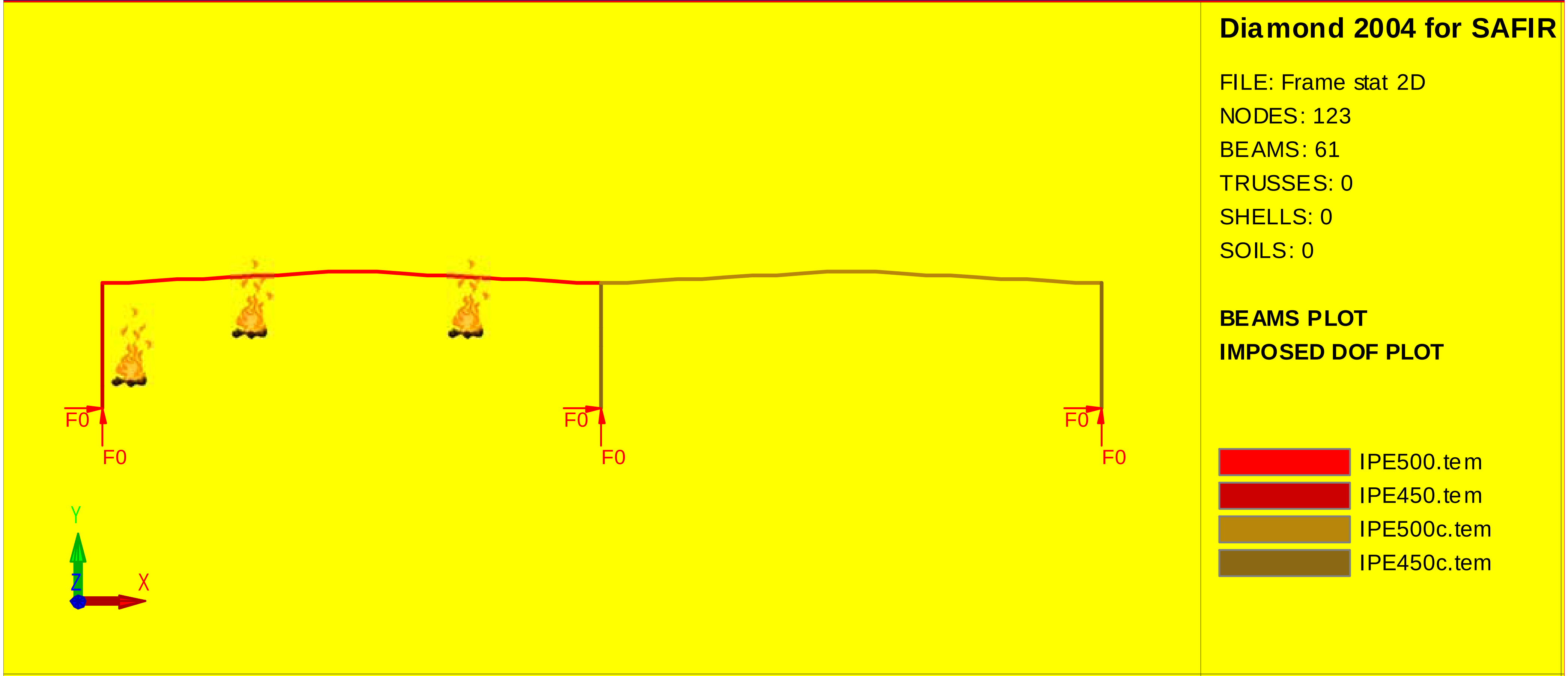
$$\{F\} = [K]\{u\} + [C]\{\dot{u}\} + [M]\{\ddot{u}\}$$

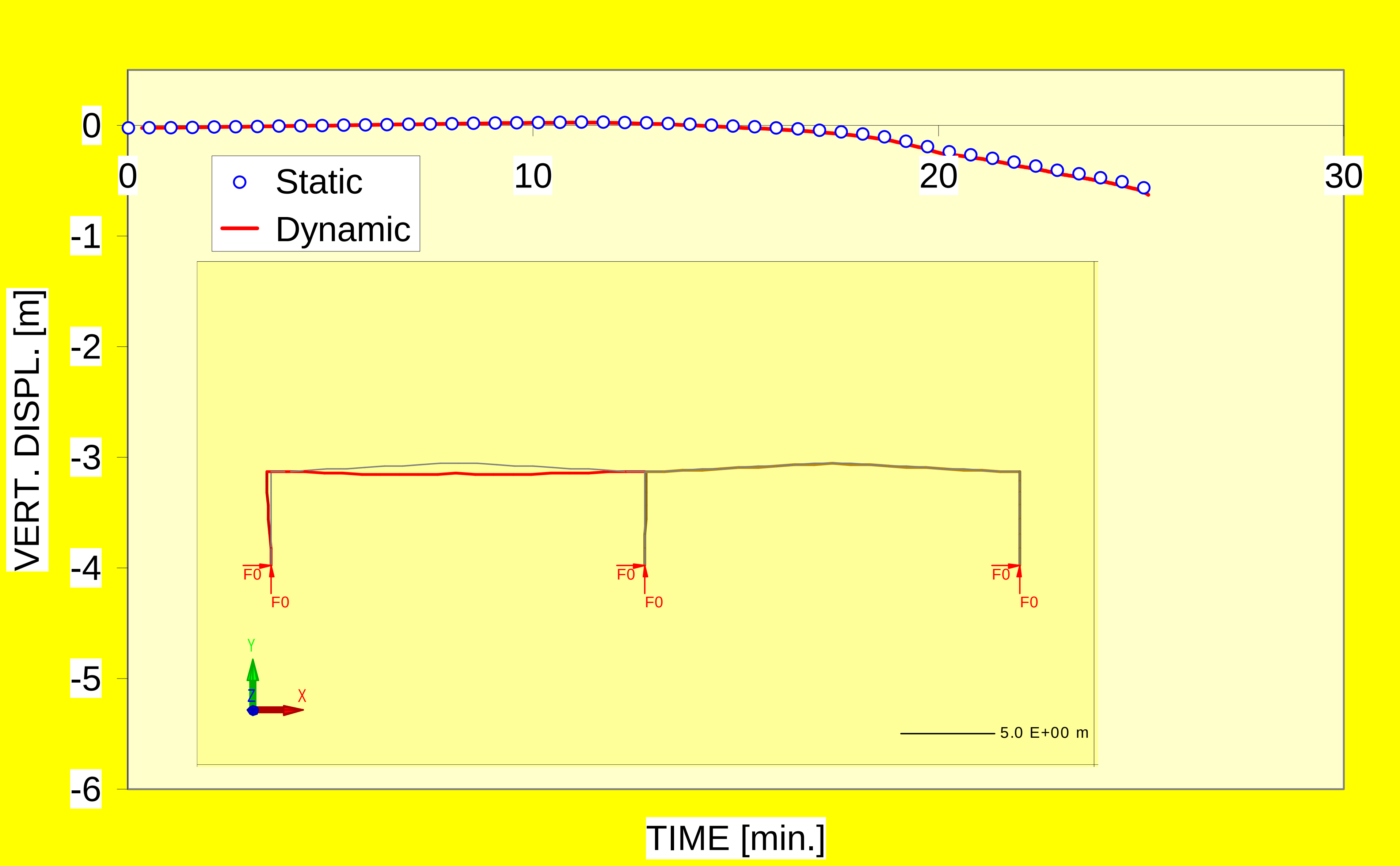
Lee's Frame Analysed with Shell F.E. in bending
dT/dt = 1°C/s



Other considerations

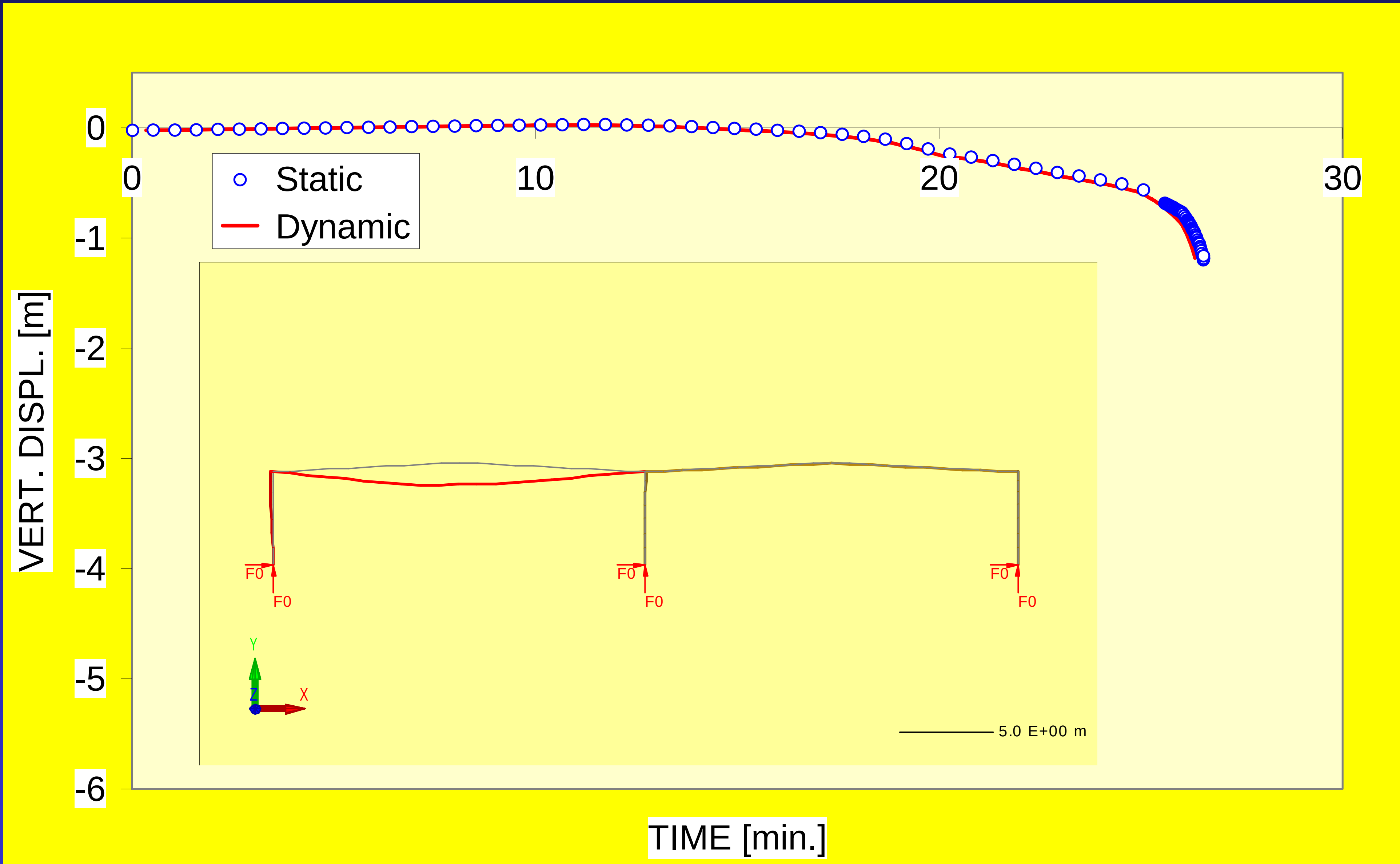
Failure mode may be more critical than time of collapse





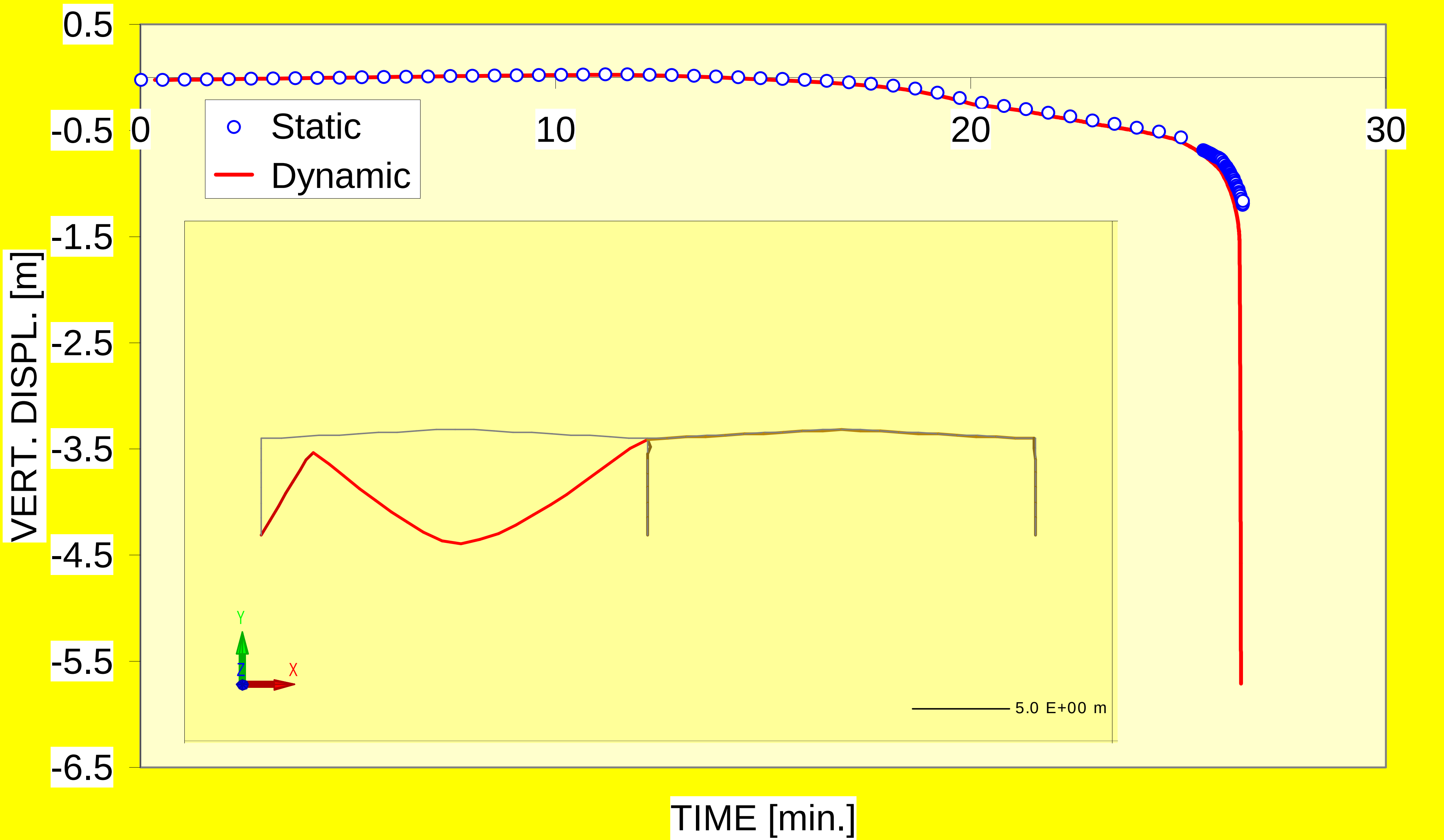
0
-1
-2
-3
-4
-5
-6
VERT. DISPL. [m]
0
10
20
30
Static
Dynamic
F0
F0
F0
F0
F0
F0
Y
Z
X
5.0 E+00 m
TIME [min.]

***t* = 25'**



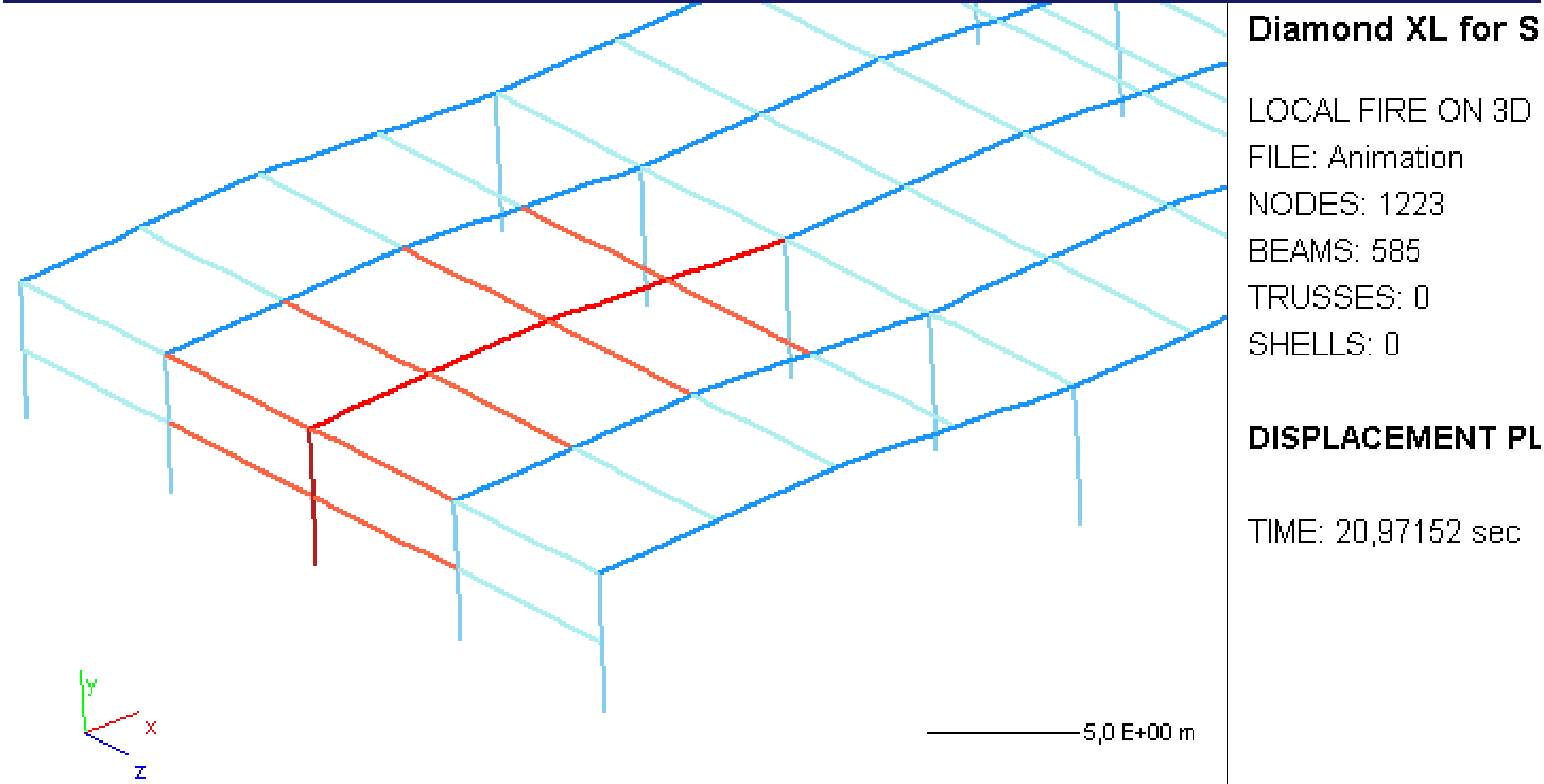
0
-1
-2
-3
-4
-5
-6
VERT. DISPL. [m]
0
10
20
30
TIME [min.]
Static
Dynamic
F0
F0
F0
F0
F0
F0
Y
Z
X
5.0 E+00 m

***t* = 26’30”**


0.5
-0.5
-1.5
-2.5
-3.5
-4.5
-5.5
-6.5
VERT. DISPL. [m]
0
10
20
30
TIME [min.]
Static
Dynamic
Y
Z
X
5.0 E+00 m

***t* = 26’34”**

The same, now in 3D, with heated purlins



3D frame (no amplification in the deformation)

When performing a S.i.F. analysis:

- ✓ make it simple,

- ✓ or not,

but not both.

Natural fire with cooling phase.

Criteria?

- Time of collapse (natural fire) > required time for evacuation
- Infinite resistance (until complete burn out) ?
- Time of collapse (natural fire) = R(ISO) ?

Stupidity?

Or maybe not!

Representation of the fire ?

Nominal fire curve?

OK for structural research in the heating phase

Post-flashover parametric fire curve?

OK for structural research with a cooling phase

Zone models?

Ok if the geometry is appropriate

Difficulty for the columns in multi zone models

Representation of the fire ?

Local models (Hasemi)?

OK if the geometry is appropriate

Hasemi not applicable for columns

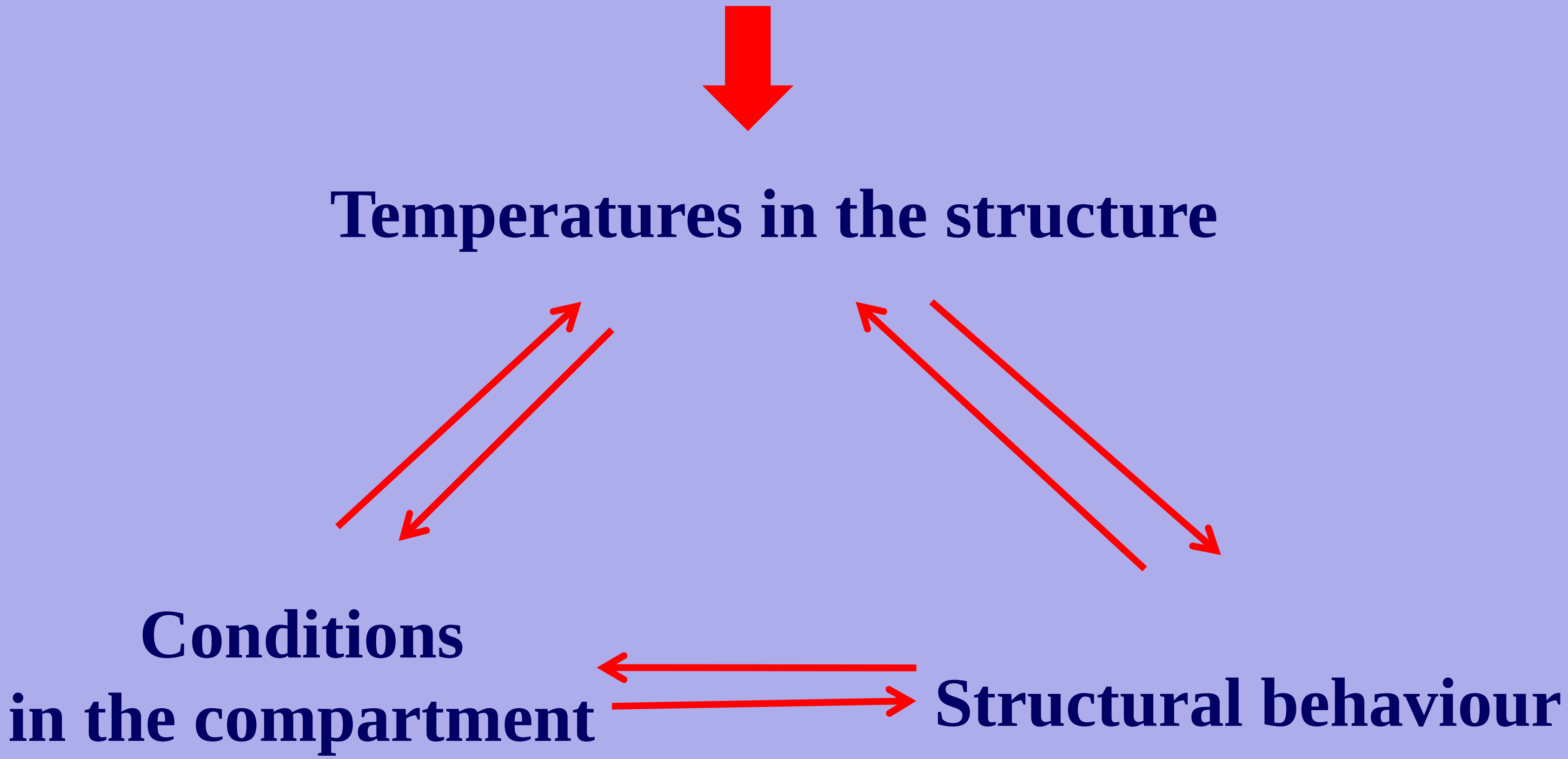
CFD

Not for post-flashover fires

OK when local fire, large compartment with complex geometry, big budget.

Which interactions to consider?

IN REALITY EVERYTHING IS COUPLED



Structural fire engineering used in practice to:

1) Prove stability without any protection on steel

2) Reduce fire protection on steel

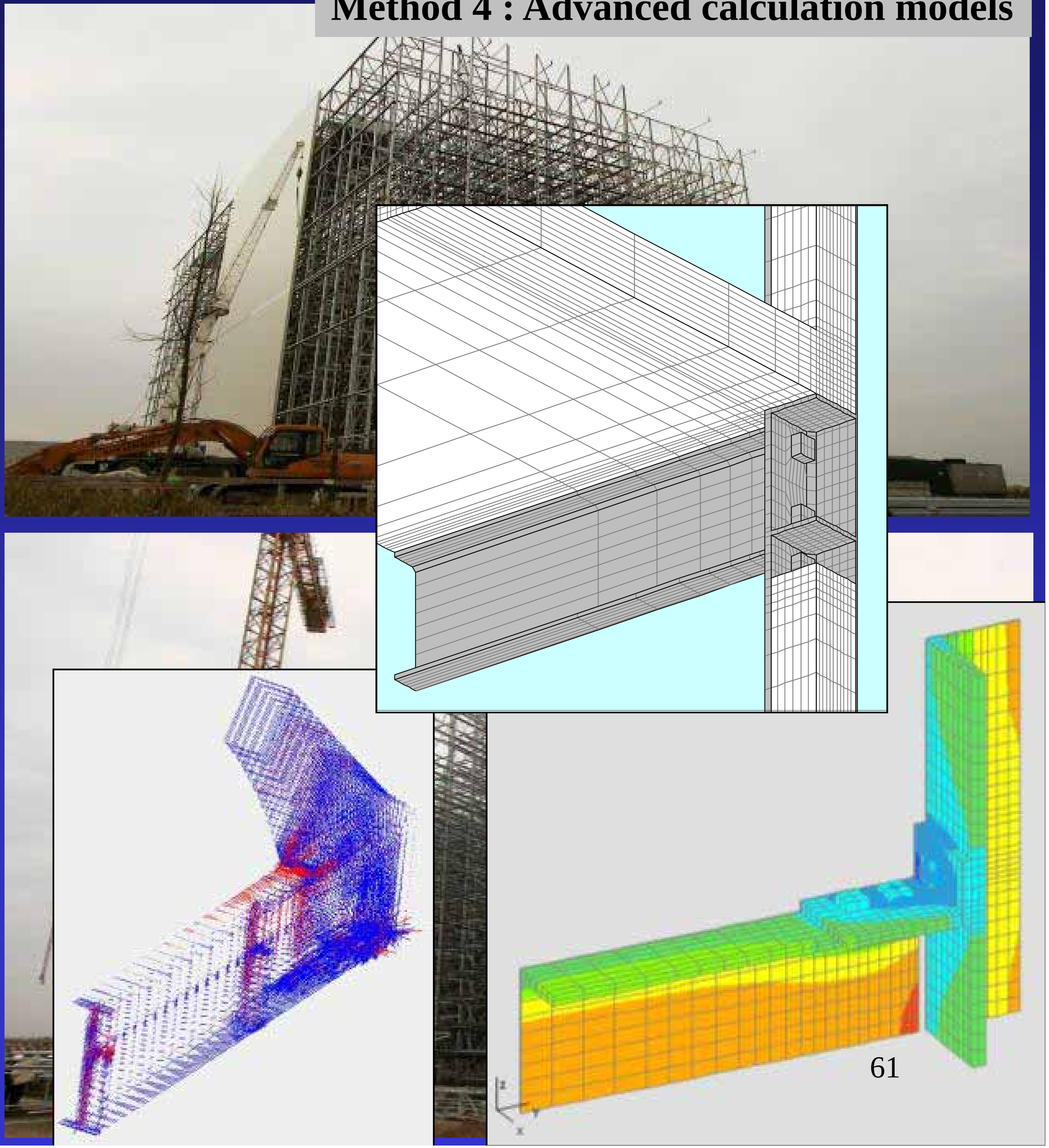
3) Prove fire resistance of existing concrete structure

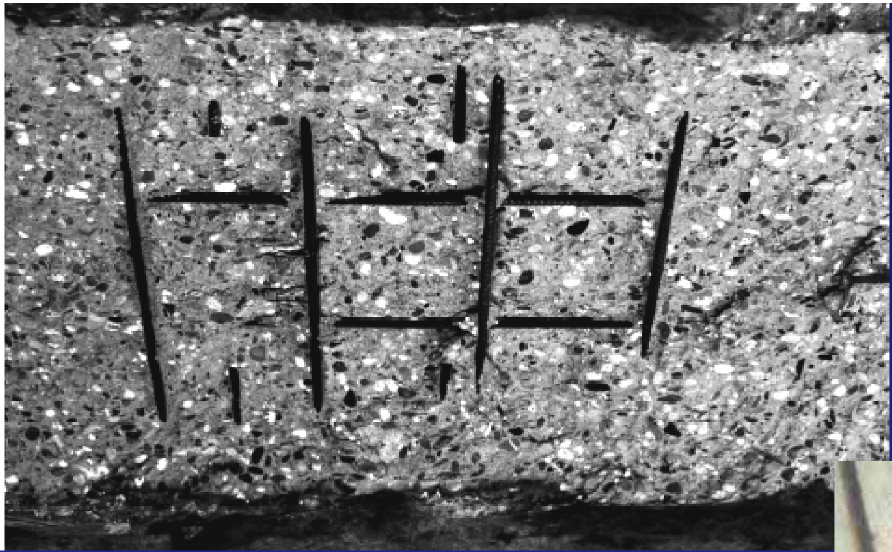
4) Prove failure mode

Method 4 : Advanced calculation models

Tomorrow?

- Very large models
- Connections
- Spalling of concrete



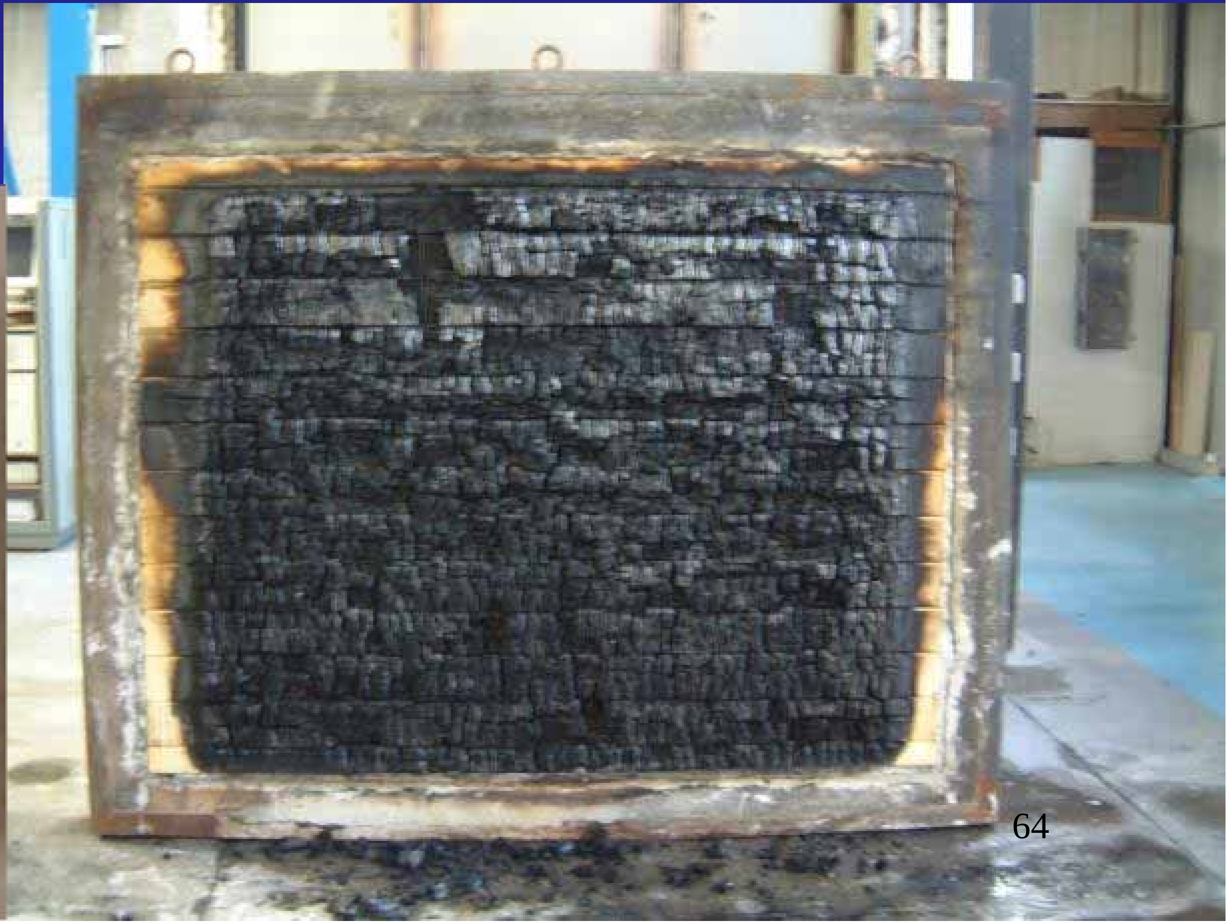


Tomorrow?

- **C.F.D. - F.E. interconnection**

Tomorrow

- Moisture movements (e.g. in wood)
- Mechanical properties of gypsum
- Shear strength of concrete
- …



Thank you and …... Fly high!