SAFIR®
A software for modelling the behaviour of structures subjected to the fire

Course by

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SAFIR

Dynamic analyses

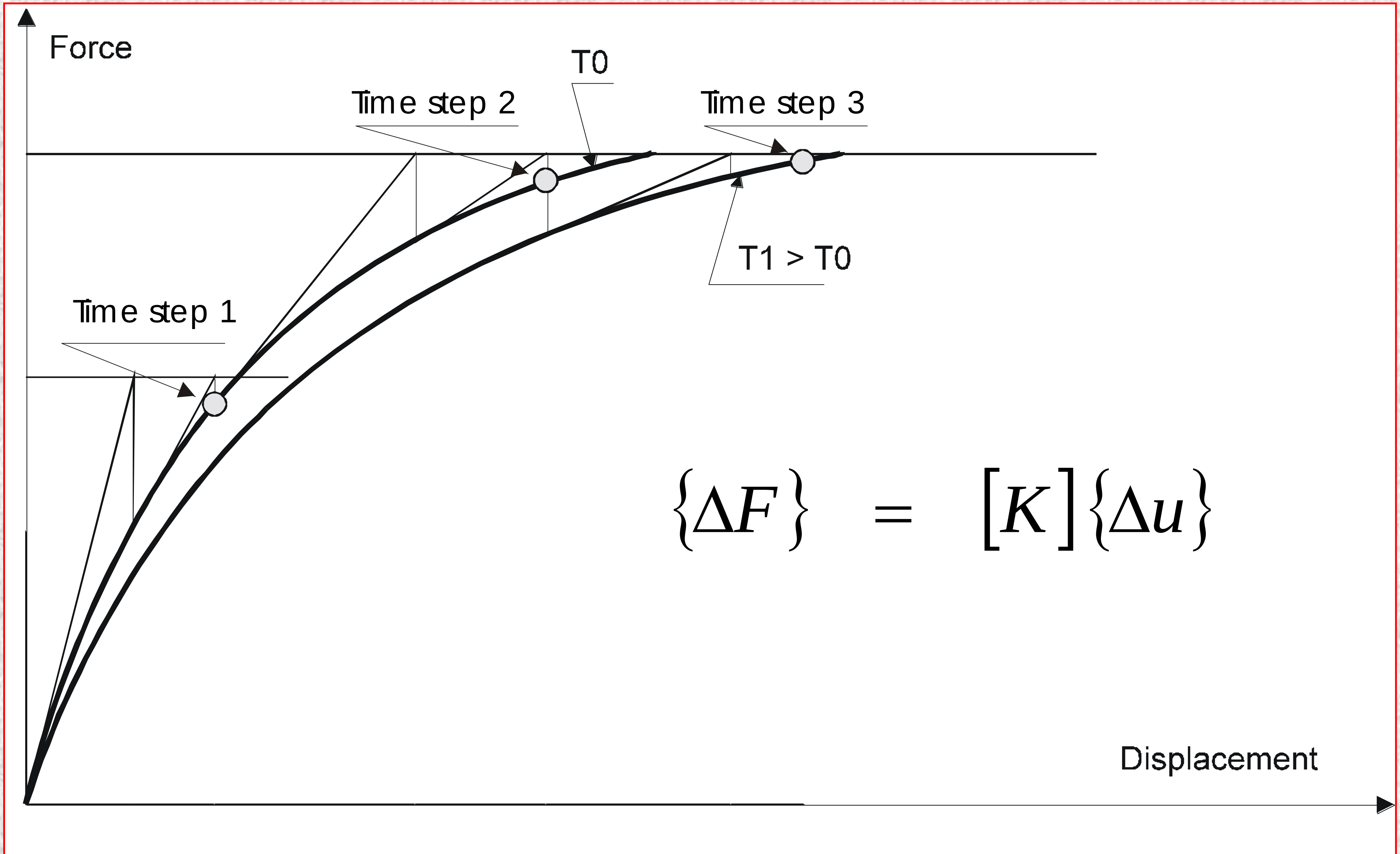
Three steps
in the structural fire design:

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

2. *Calculate the temperatures in the structure.*

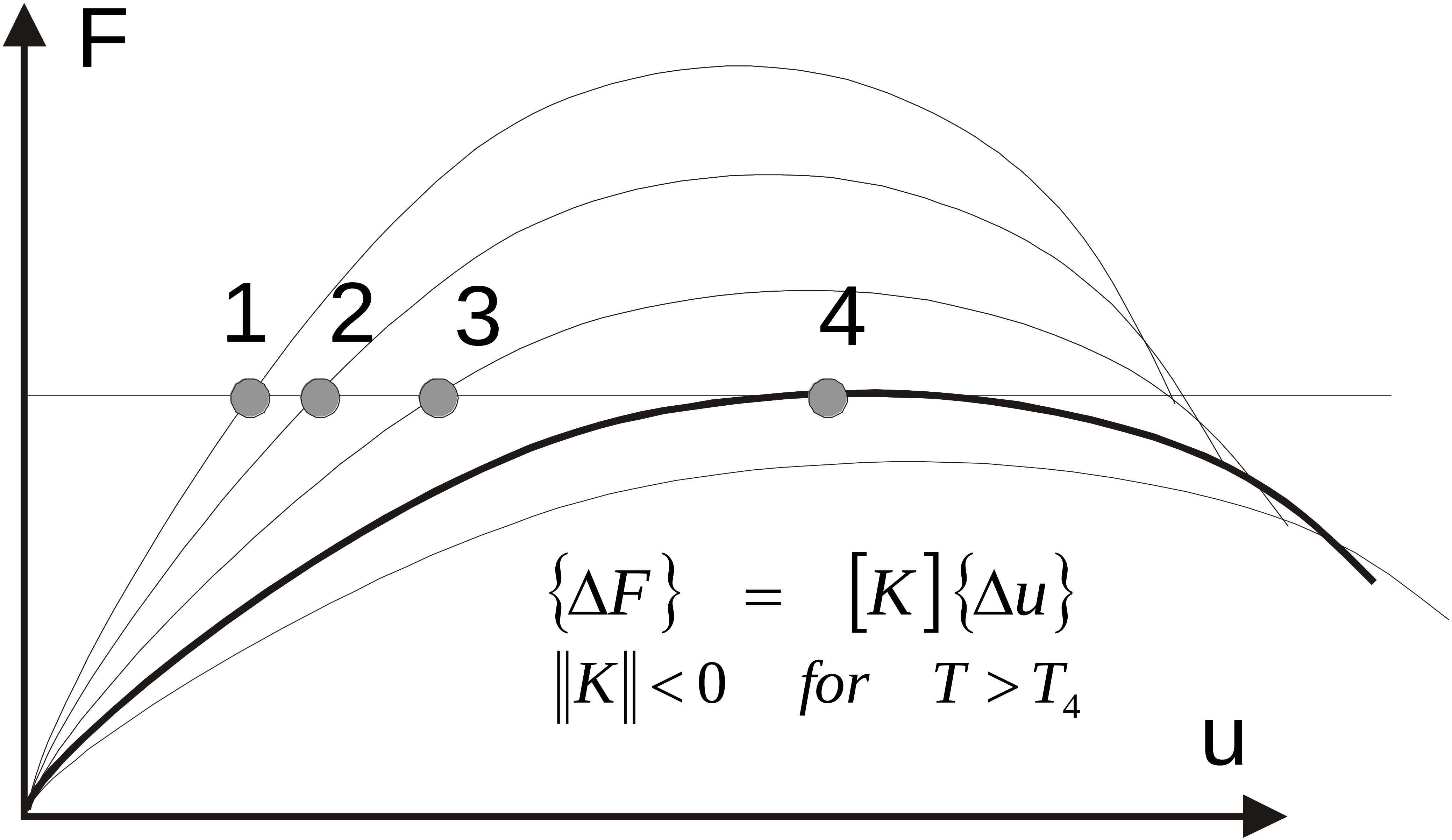
3. ***Calculate the mechanical behaviour.***

Successive static analyses used to take into account the temperature increase



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

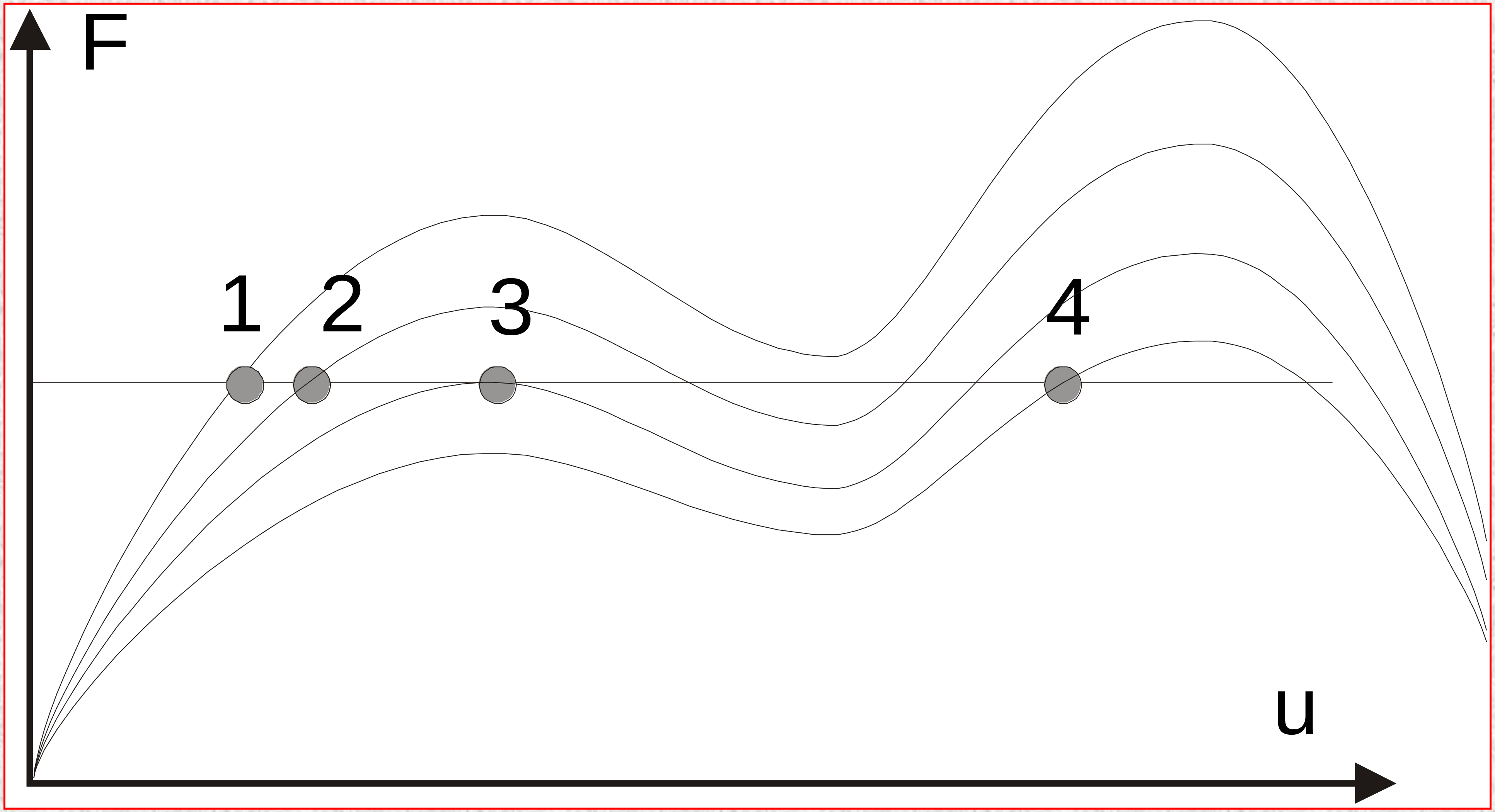
Normal evolution toward failure



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

$$\|K\| < 0 \quad for \quad T > T_4$$

Local or temporary failure at T_3



Local or temporary failure caused by:

- **geometrical reasons (buckling of one bar in a statically indeterminate sytem),**

- **material behaviour (descending branches in $\sigma-\varepsilon$ relationships, formation of plastic hinges).**

Various solutions sometimes used:

- **Remove the unstable element from the structure.**
- **Use « modified » σ–ε relationships.**
- **Use non-tangent stiffness matrix.**
- **Use « Riks » type methods (arc-length).**

These solution are numerical tricks and achieve mixed success.

Solution implemented in SAFIR: DYNAMIC ANALYSIS

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

NEWMARK method

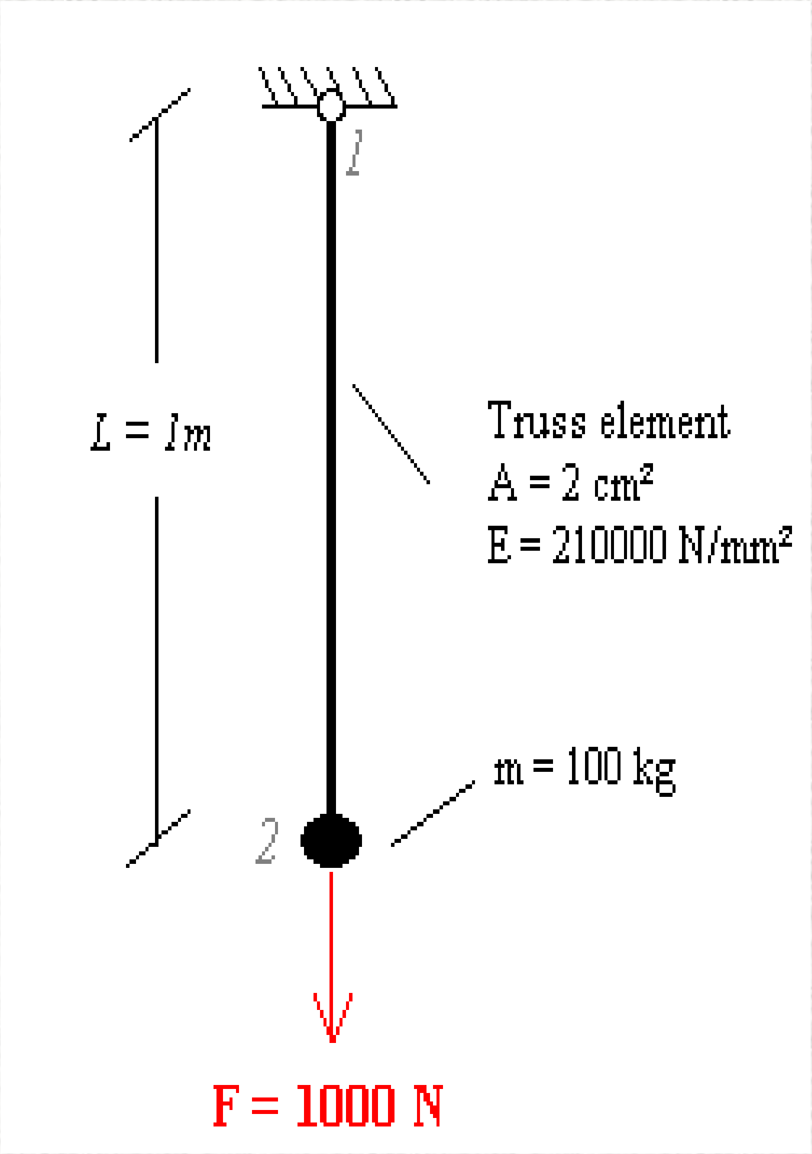
$$\{F_1\} + \{A_0\} - \{F_0\} - \{A_{-1}\} = [K^*]\{\Delta u_1\}$$

with $$[K^*] = [K] + \frac{\delta}{\alpha\,\Delta t}[C] + \frac{1}{\alpha\,\Delta t^2}[M]$$

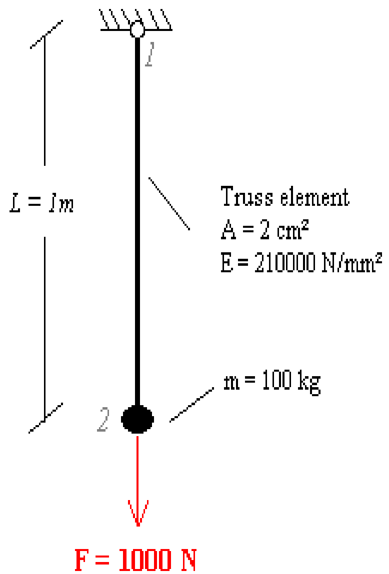
and $$\{A_0\} = \left[\frac{\delta}{\alpha\,\Delta t}\{u_0\} + \left(\frac{\delta}{\alpha} - 1\right)\{\dot{u}_0\} + \left(\frac{\delta}{2\alpha} - 1\right)\{\ddot{u}_0\}\right][C] + \left[\frac{1}{\alpha\,\Delta t^2}\{u_0\} + \frac{1}{\alpha\,\Delta t}\{\dot{u}_0\} + \left(\frac{1}{2\alpha} - 1\right)\{\ddot{u}_0\}\right][M]$$

Case study 1 : 1D axial oscillator

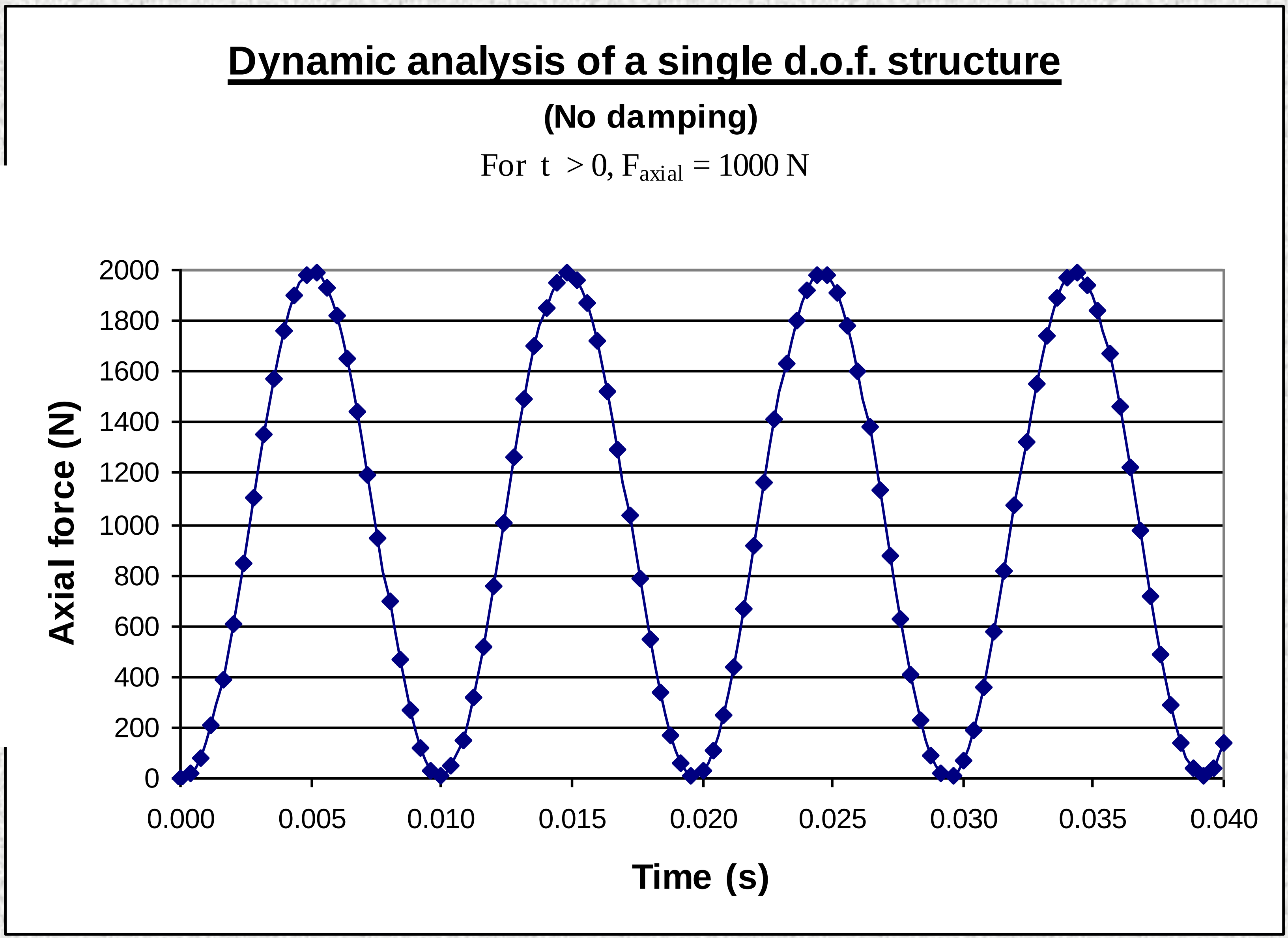
20°C, elastic



No damping

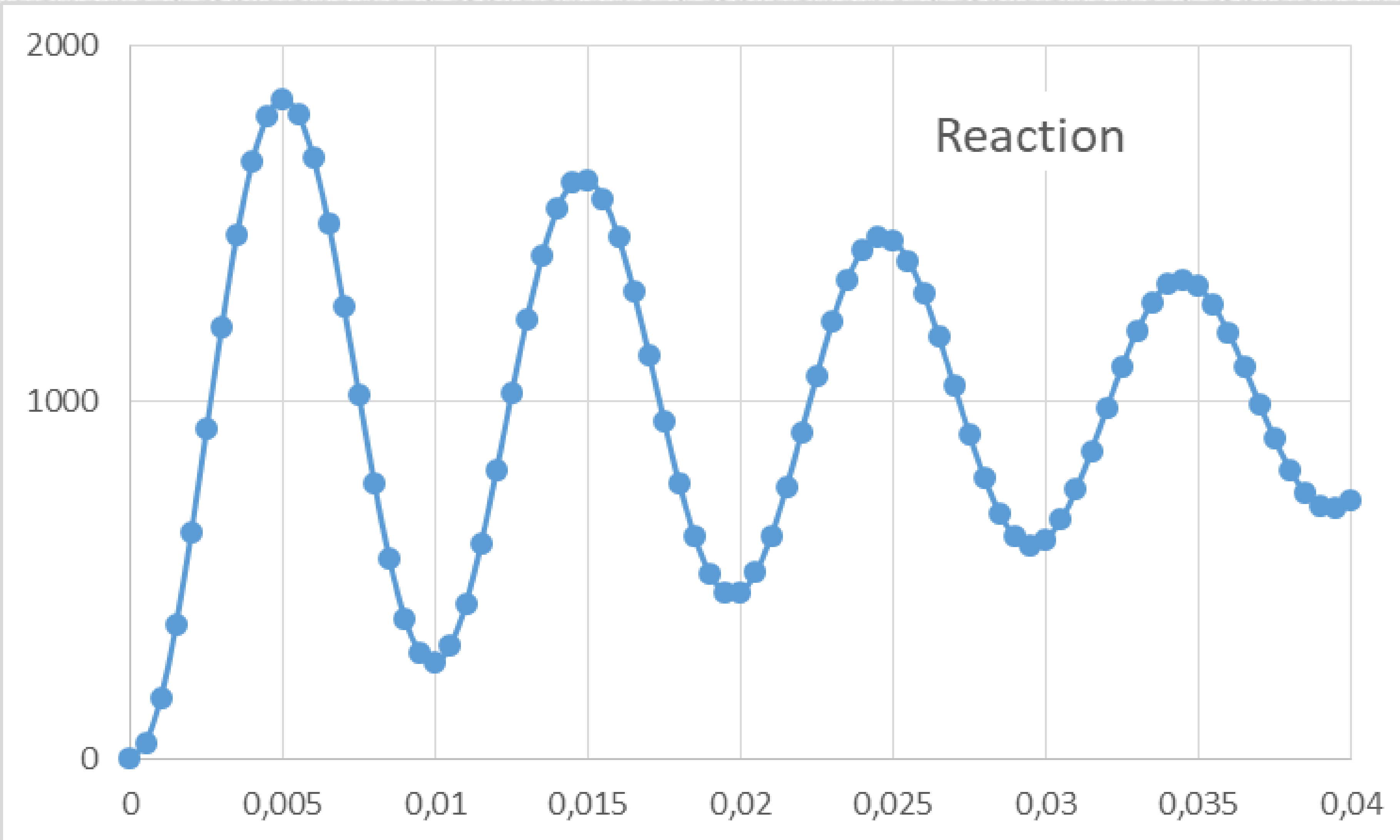


L = 1m
1
Truss element
A = 2 cm²
E = 210000 N/mm²
2
m = 100 kg
F = 1000 N



Dynamic analysis of a single d.o.f. structure
(No damping)
For t > 0, F_axial = 1000 N
Axial force (N)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0.000
0.005
0.010
0.015
0.020
0.025
0.030
0.035
0.040
Time (s)

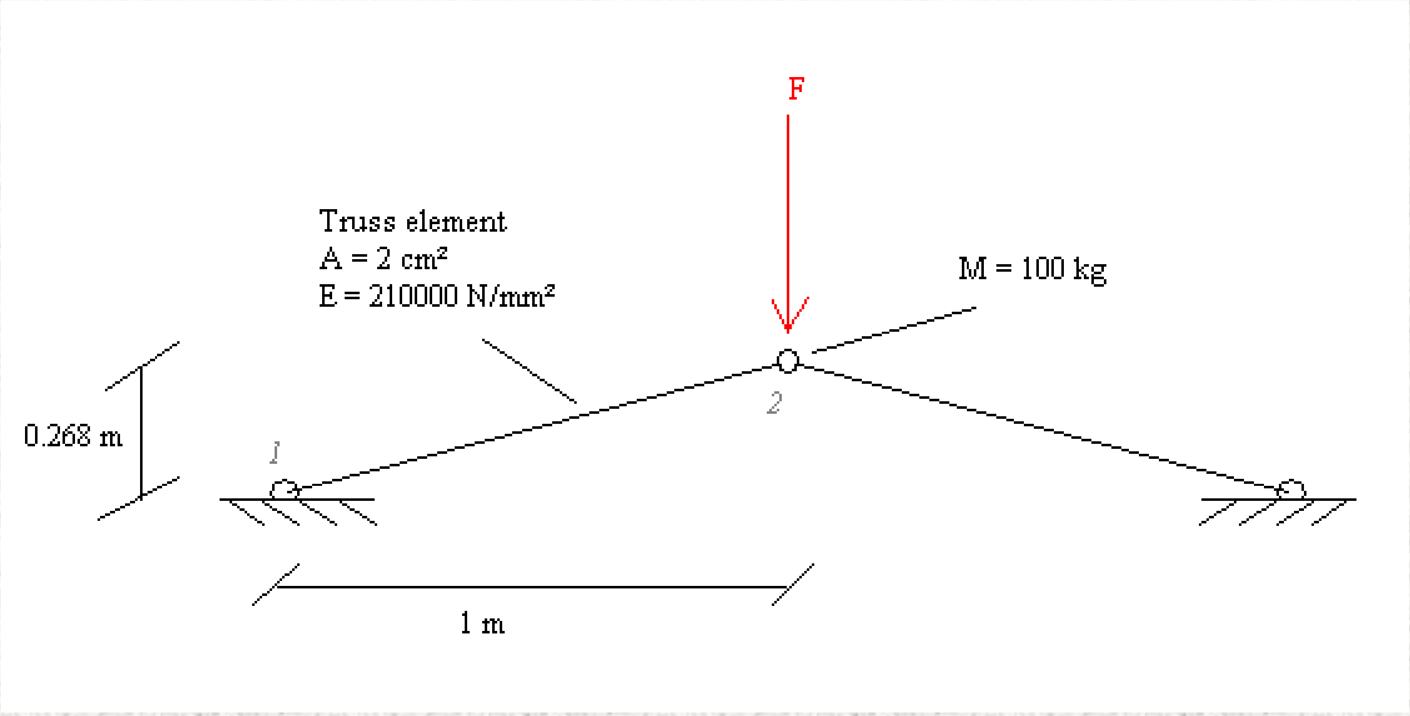
Note: in SAFIR, damping is numerical (the degree of daping depends on the size of the time steps).

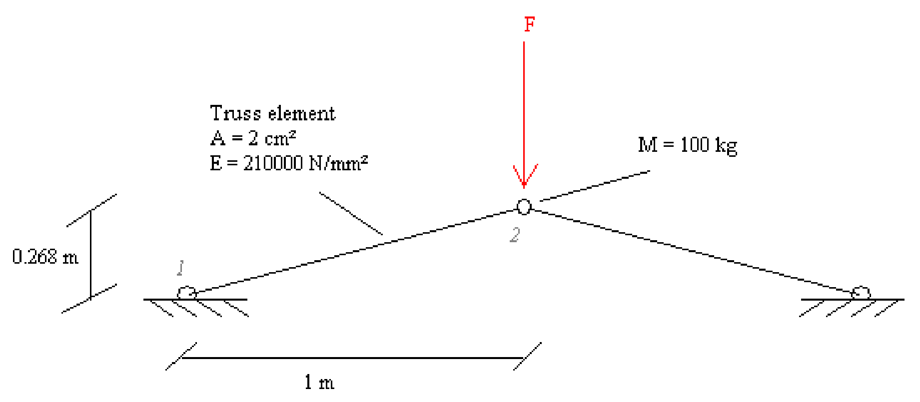


Here, damping ≈ 4,8%

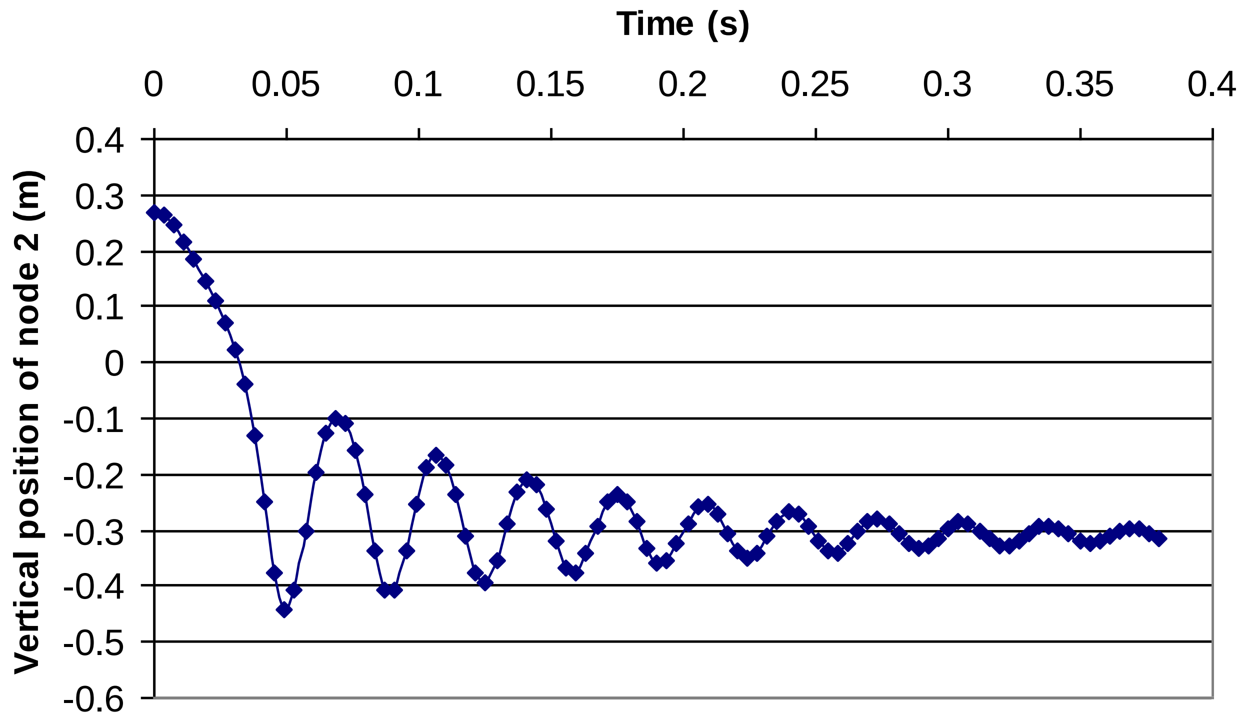
Case study 2 : 2D snap through

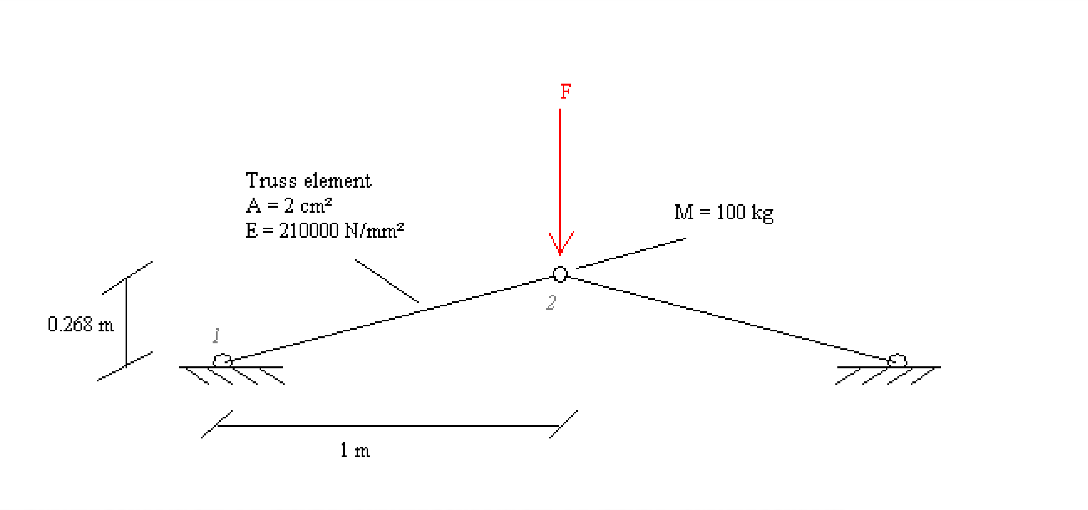
20°C, damping = 1.5%



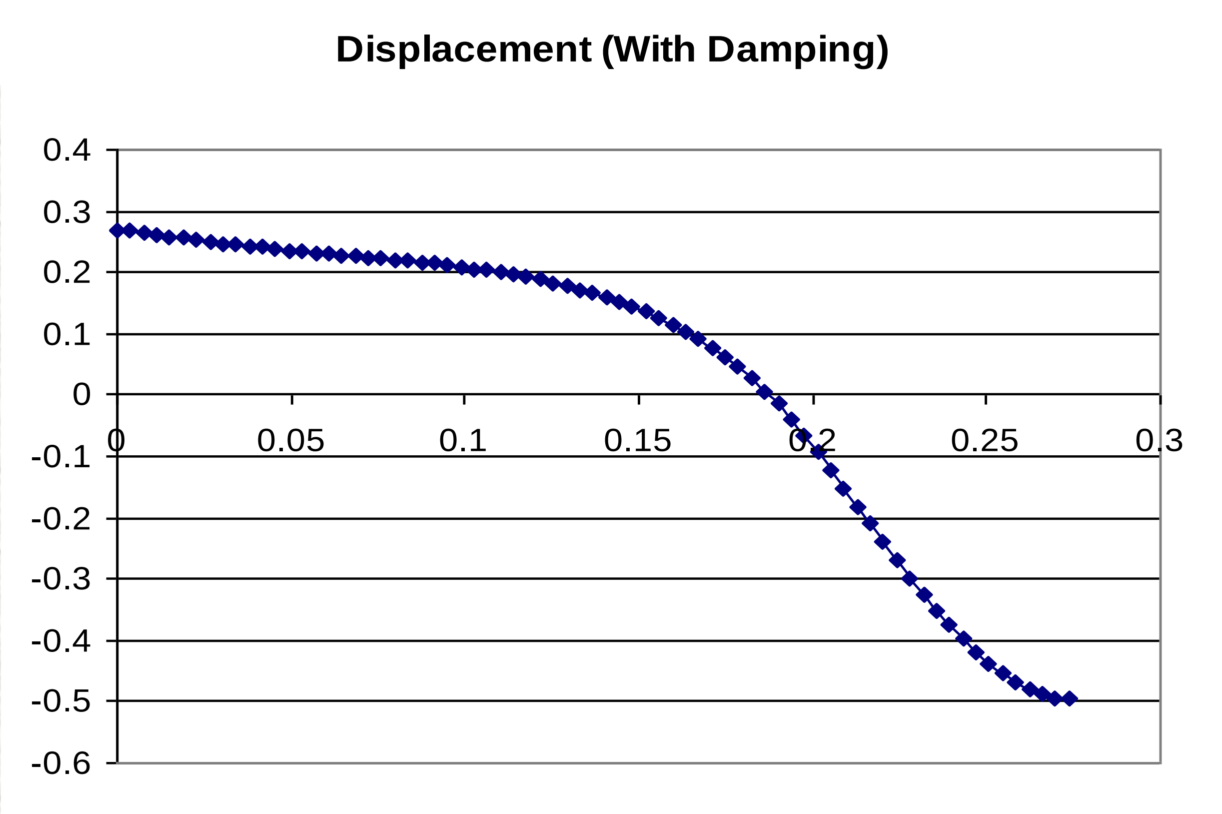

F
Truss element
A = 2 cm²
E = 210000 N/mm²
M = 100 kg
0.268 m
1
2
1 m

Elastic

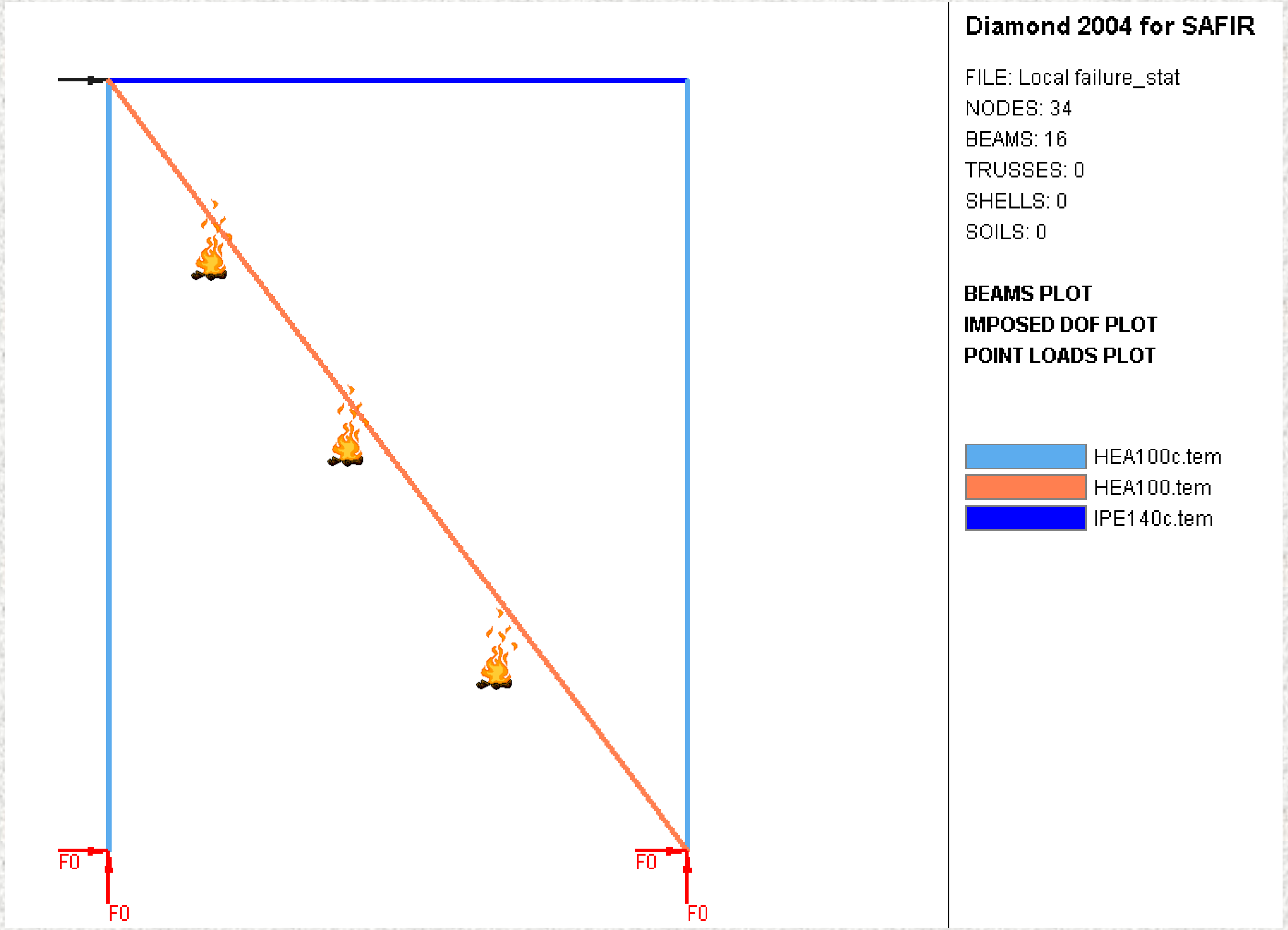

Time (s)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
Vertical position of node 2 (m)
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6



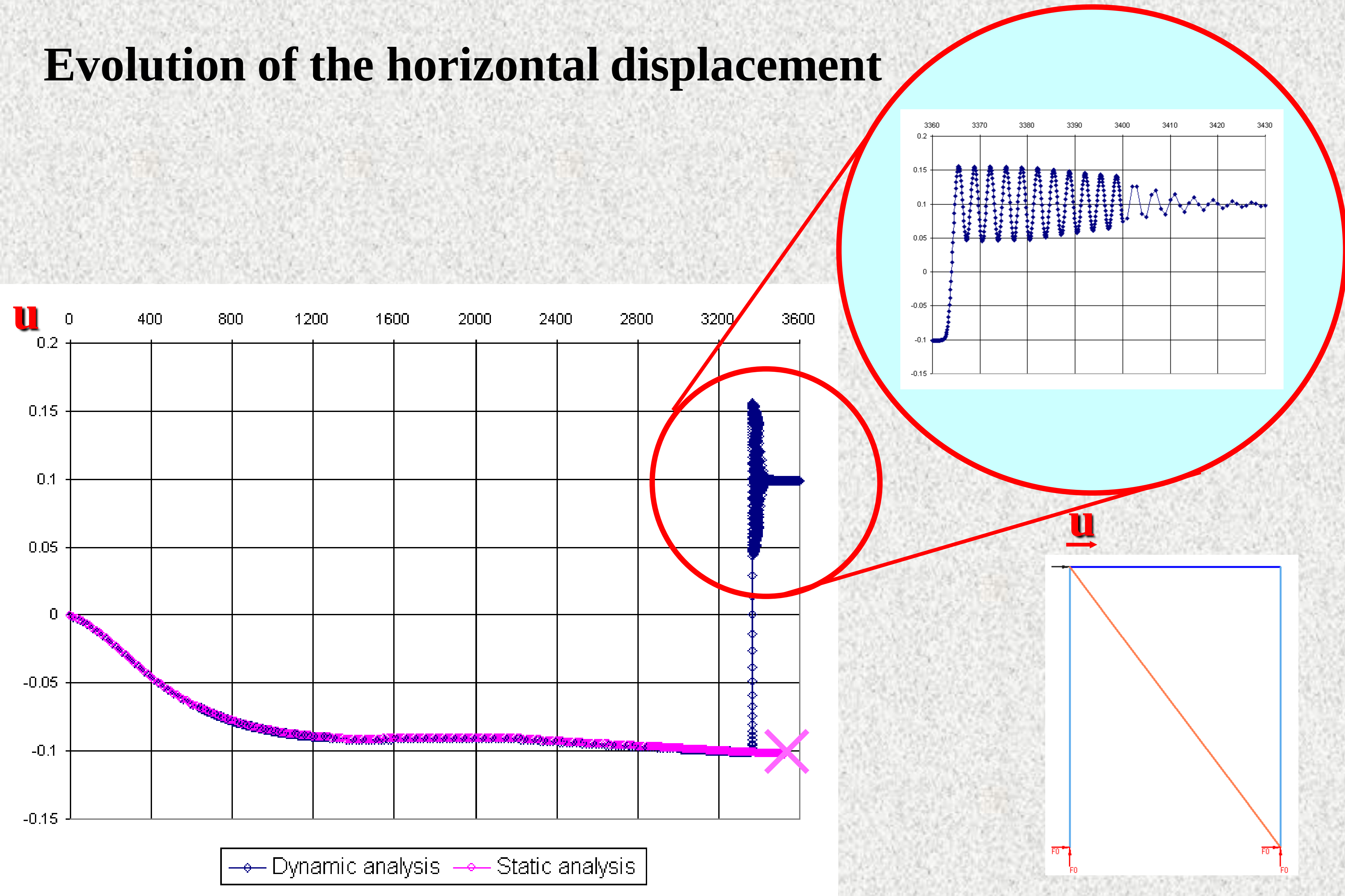
Elasto-plastic



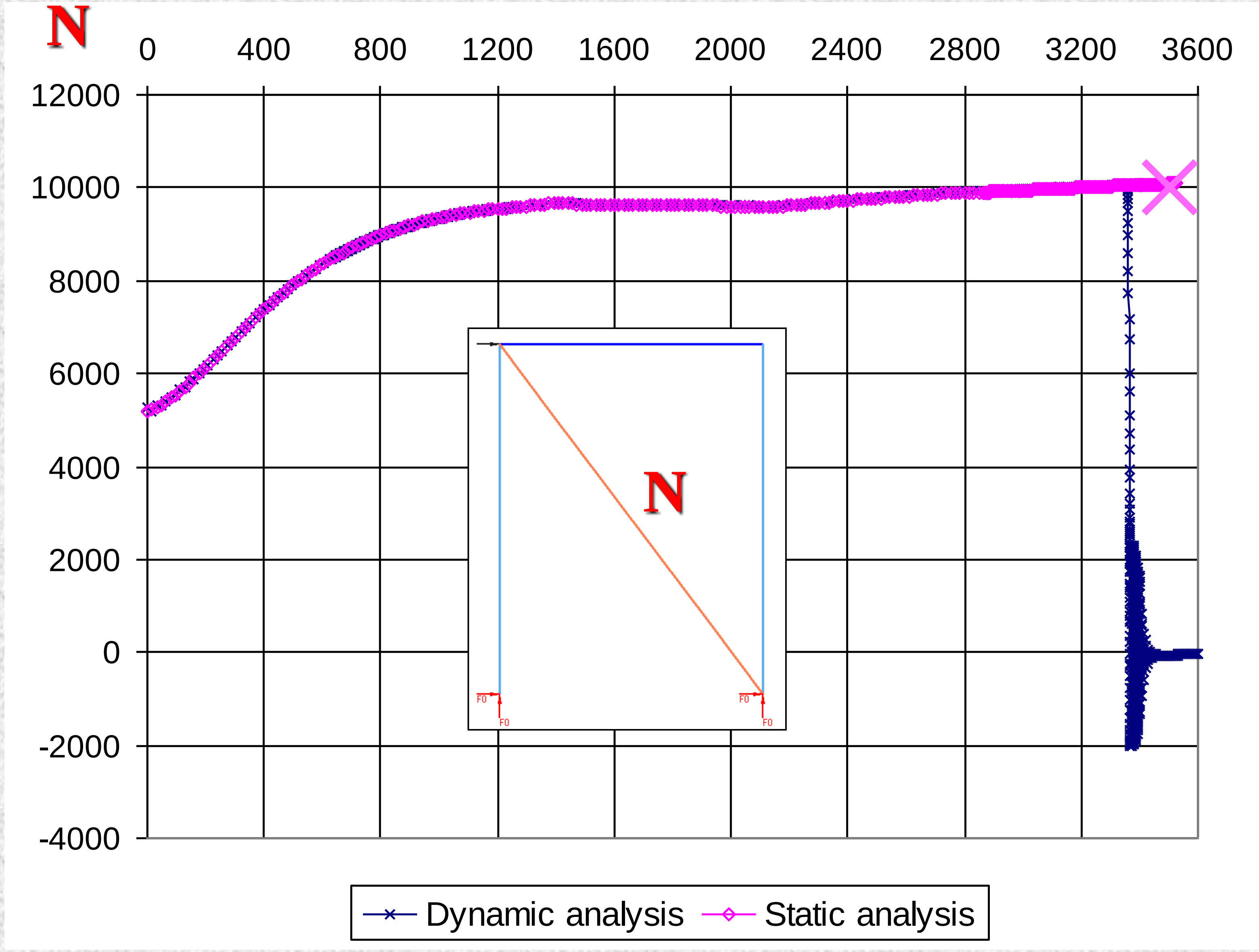
Case study 3 : EC3 steel, heated bracing in a sway frame



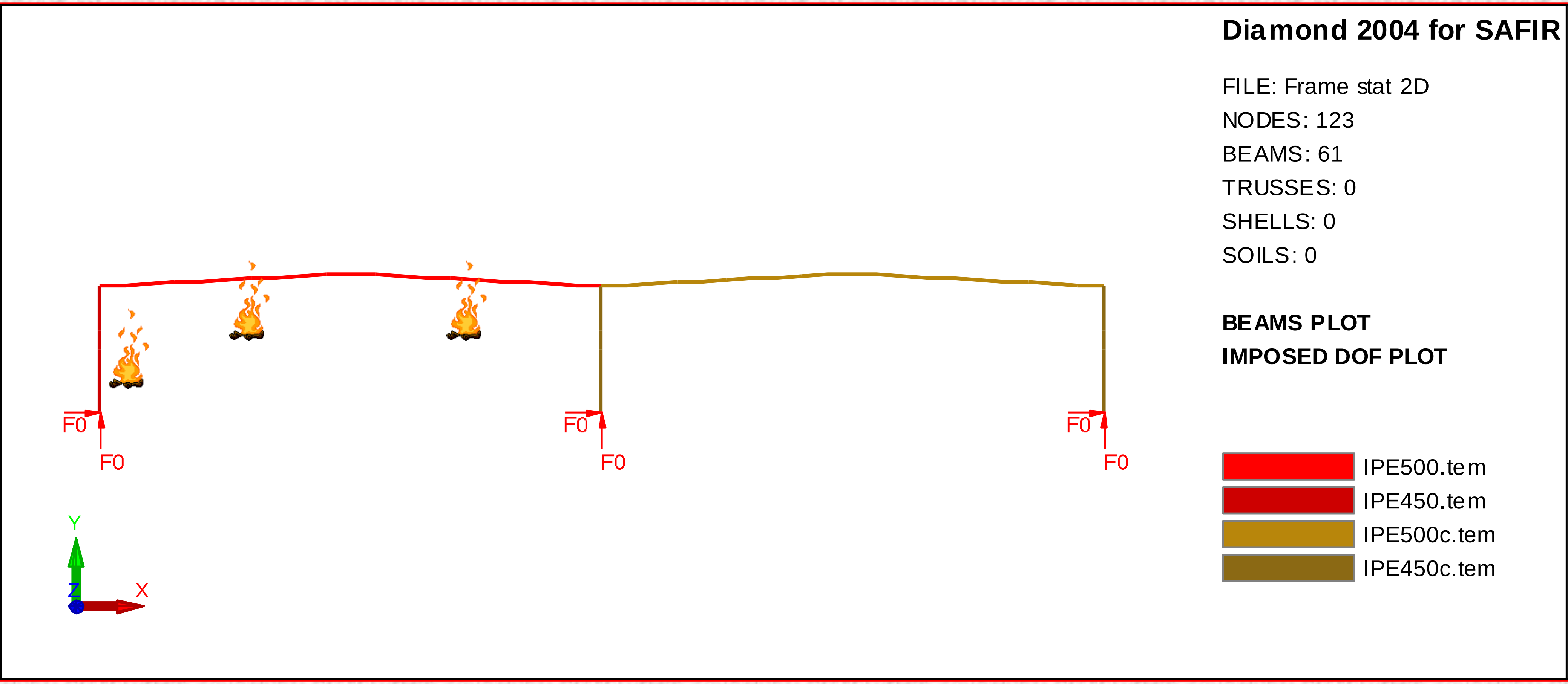
Evolution of the horizontal displacement

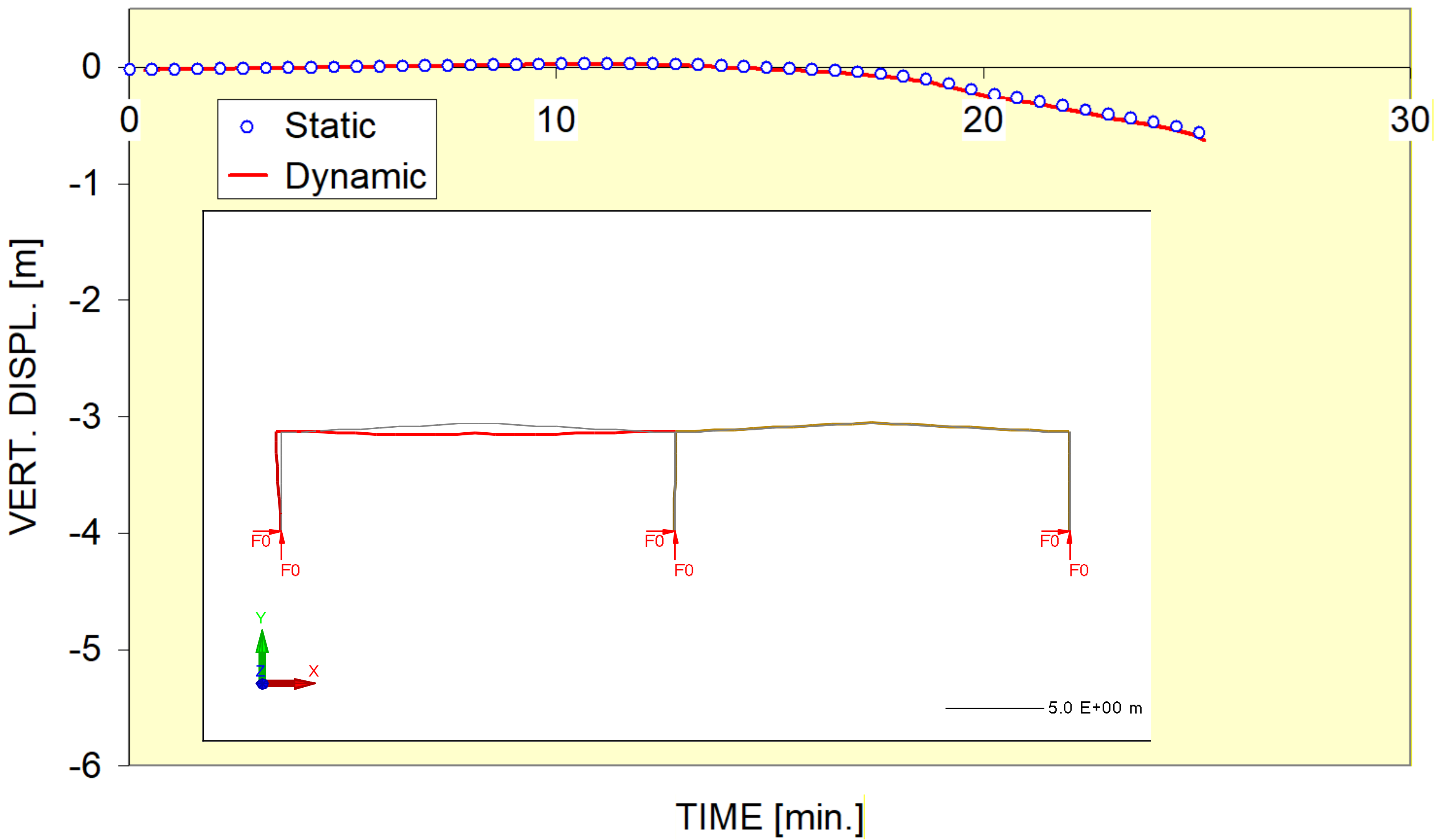


Evolution of the axial force in the diagonal

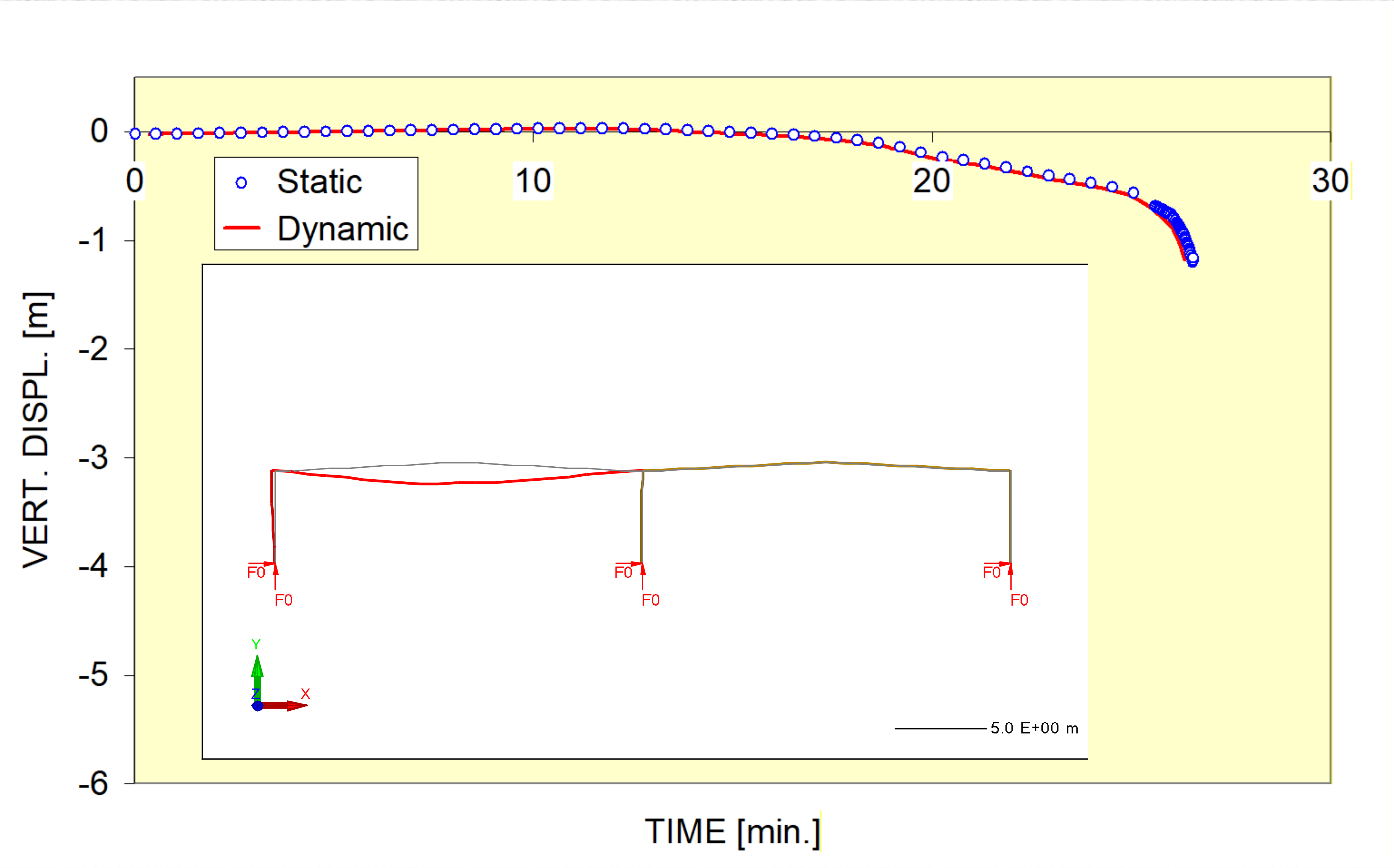


Case study 4 : EC3 steel, 1 out of 2 bays heated

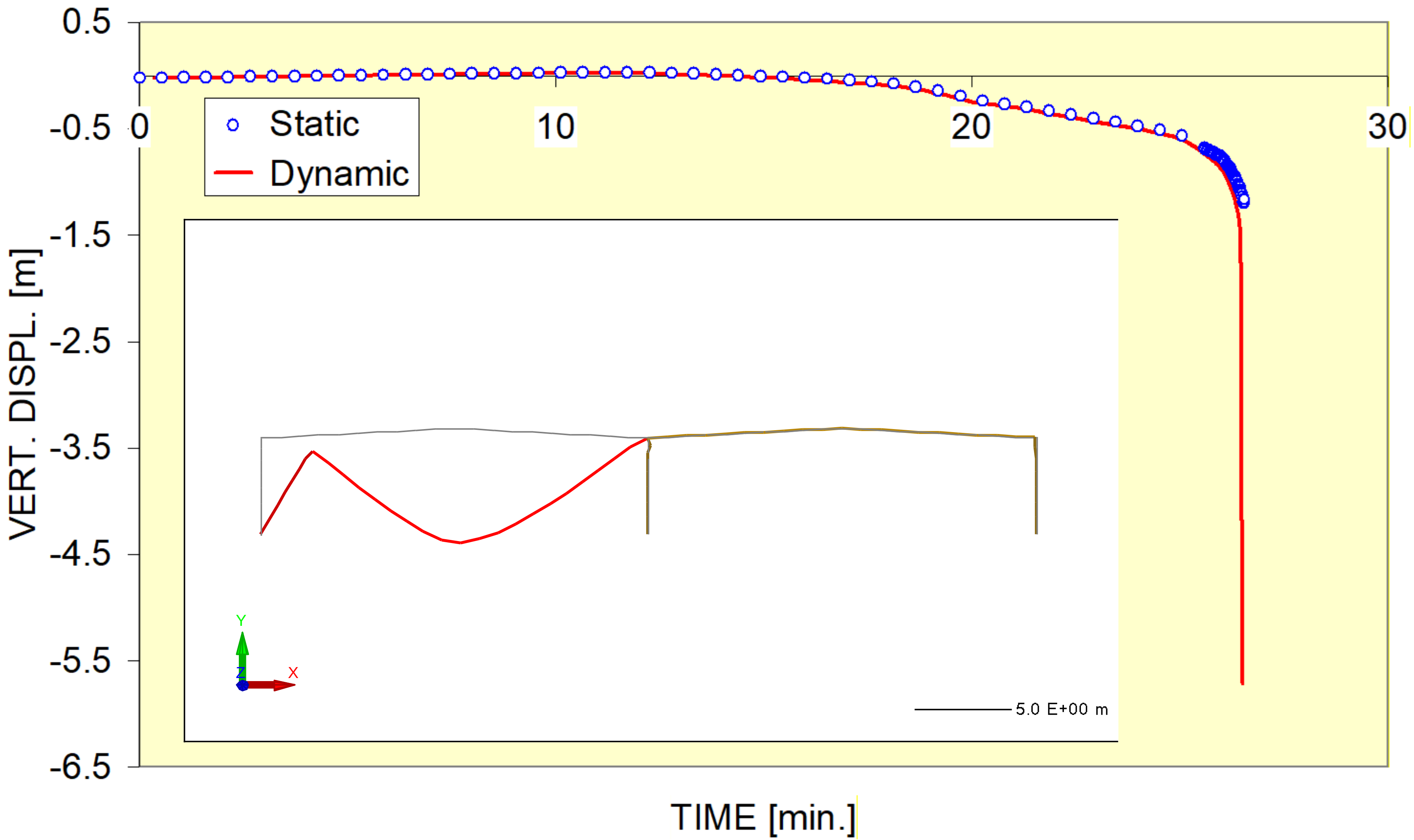




***t* = 25' (maximum lateral displacement to the left)**

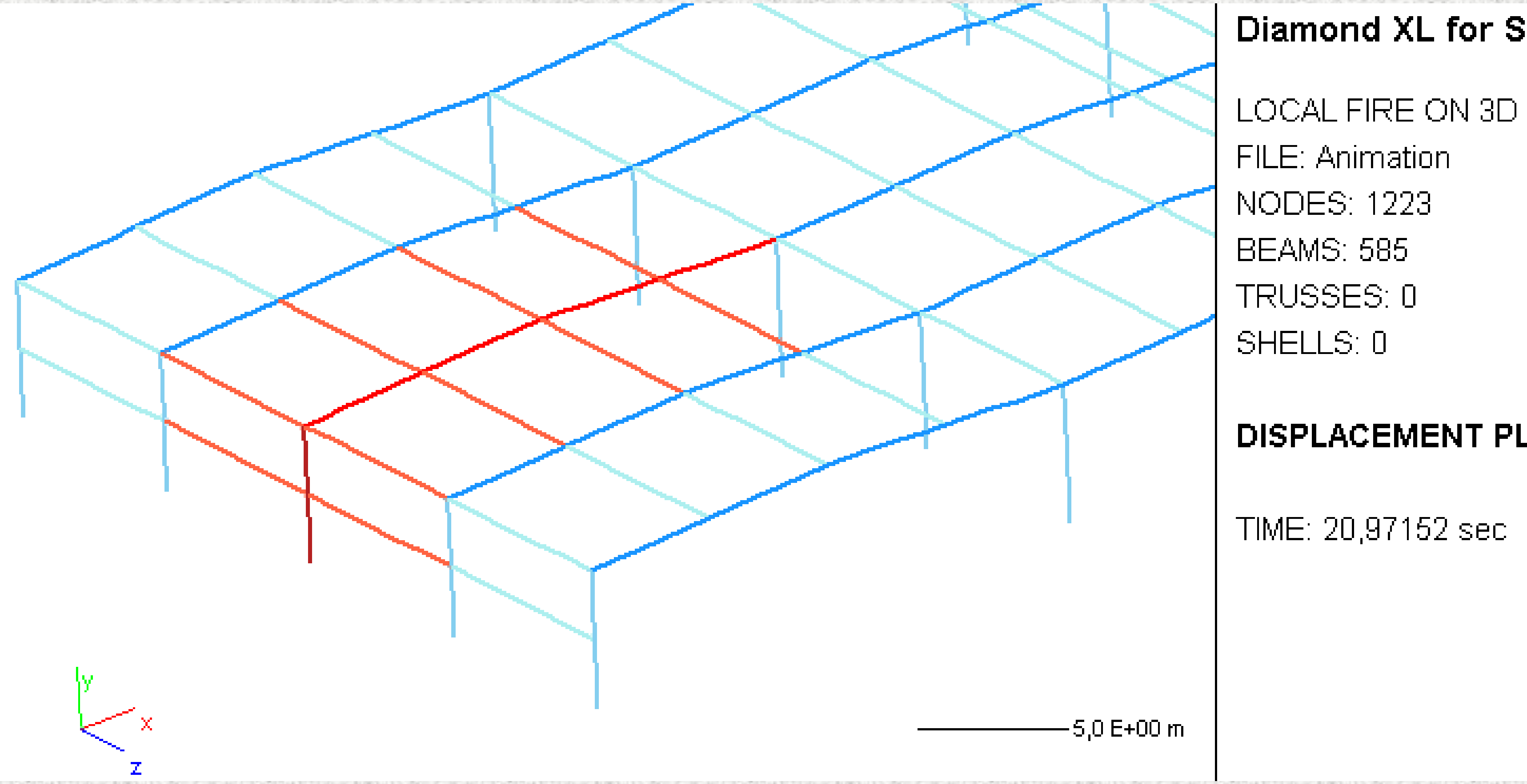


***t* = 26’30” (end of the static calculation)**



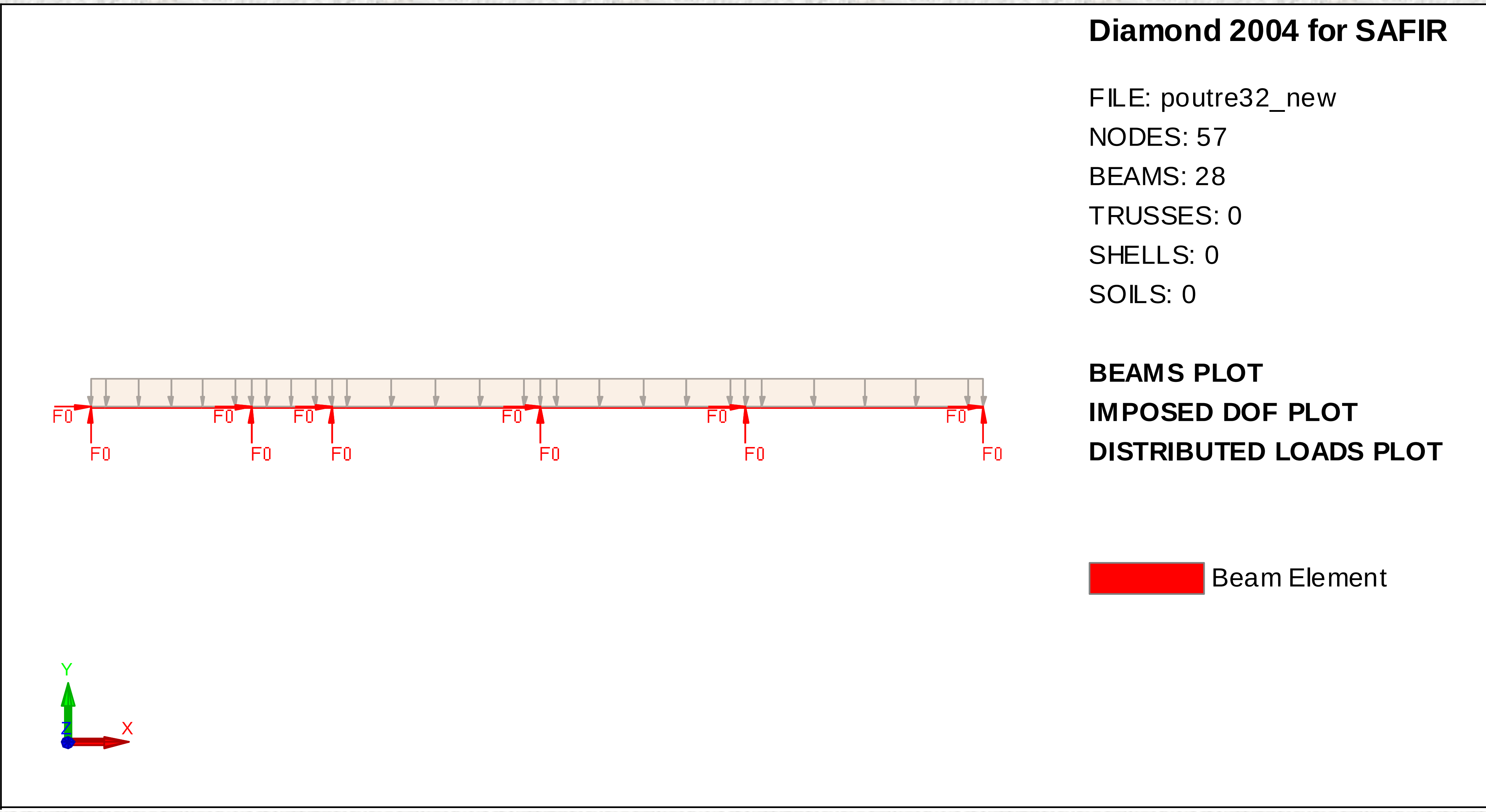
***t* = 26’34” (end of the dynamic simulation)**

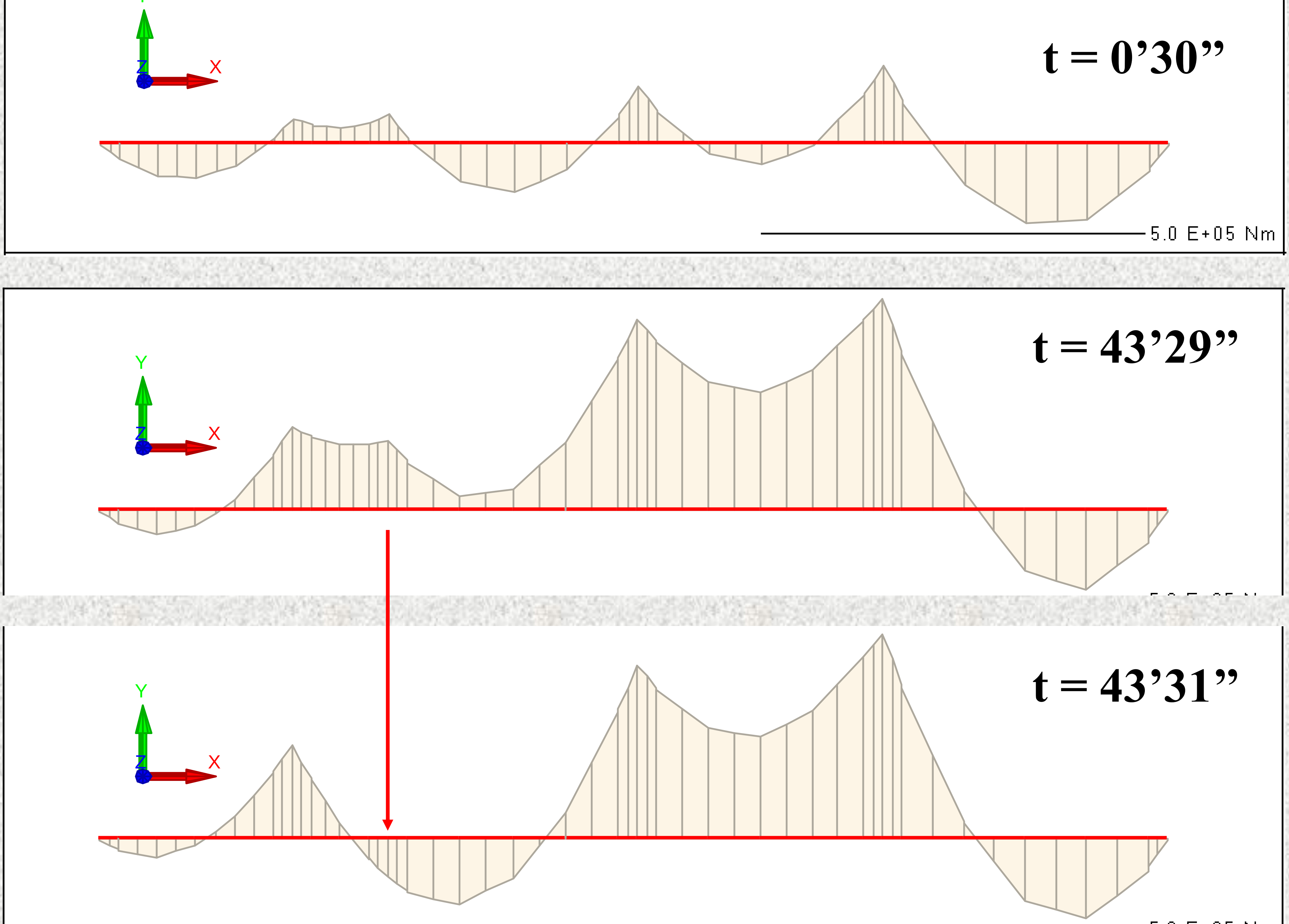
Case study 5 : The same, now in 3D, with heated purlins



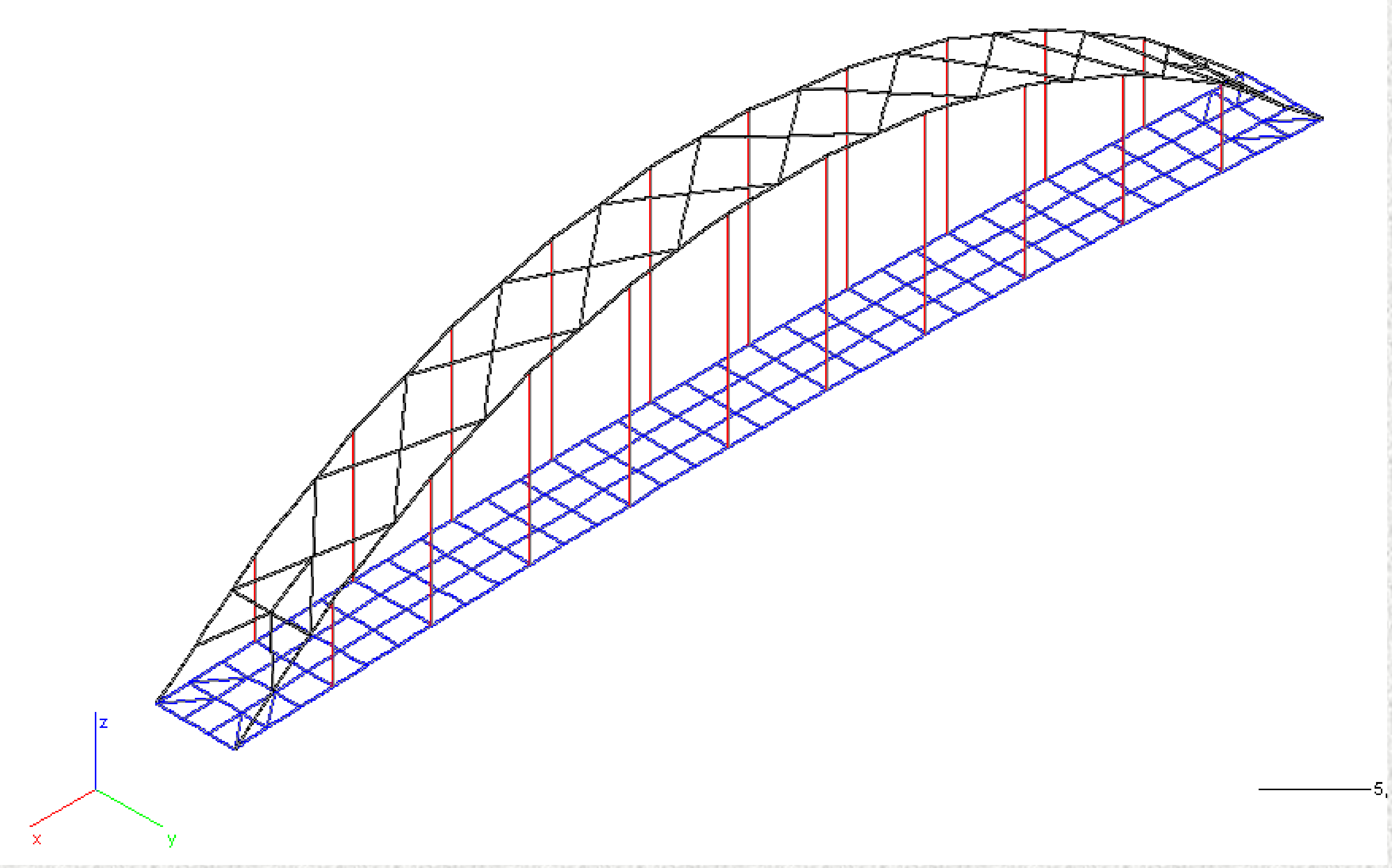
3D frame (no amplification in the deformation)

Case study 6 : Continuous reinforced concrete beam

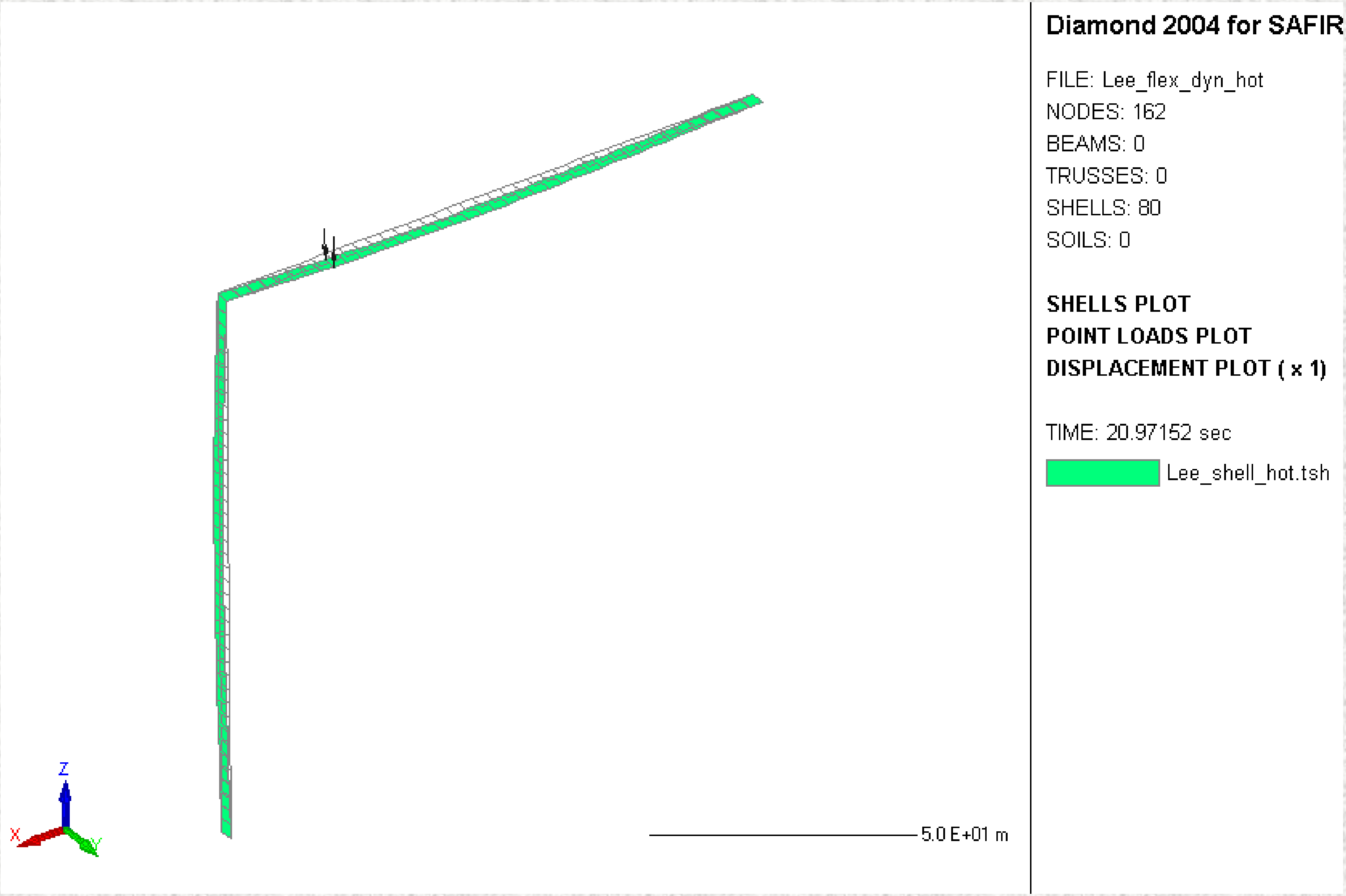



t = 0’30”
5.0 E+05 Nm
t = 43’29”
t = 43’31”
Y
Z
X

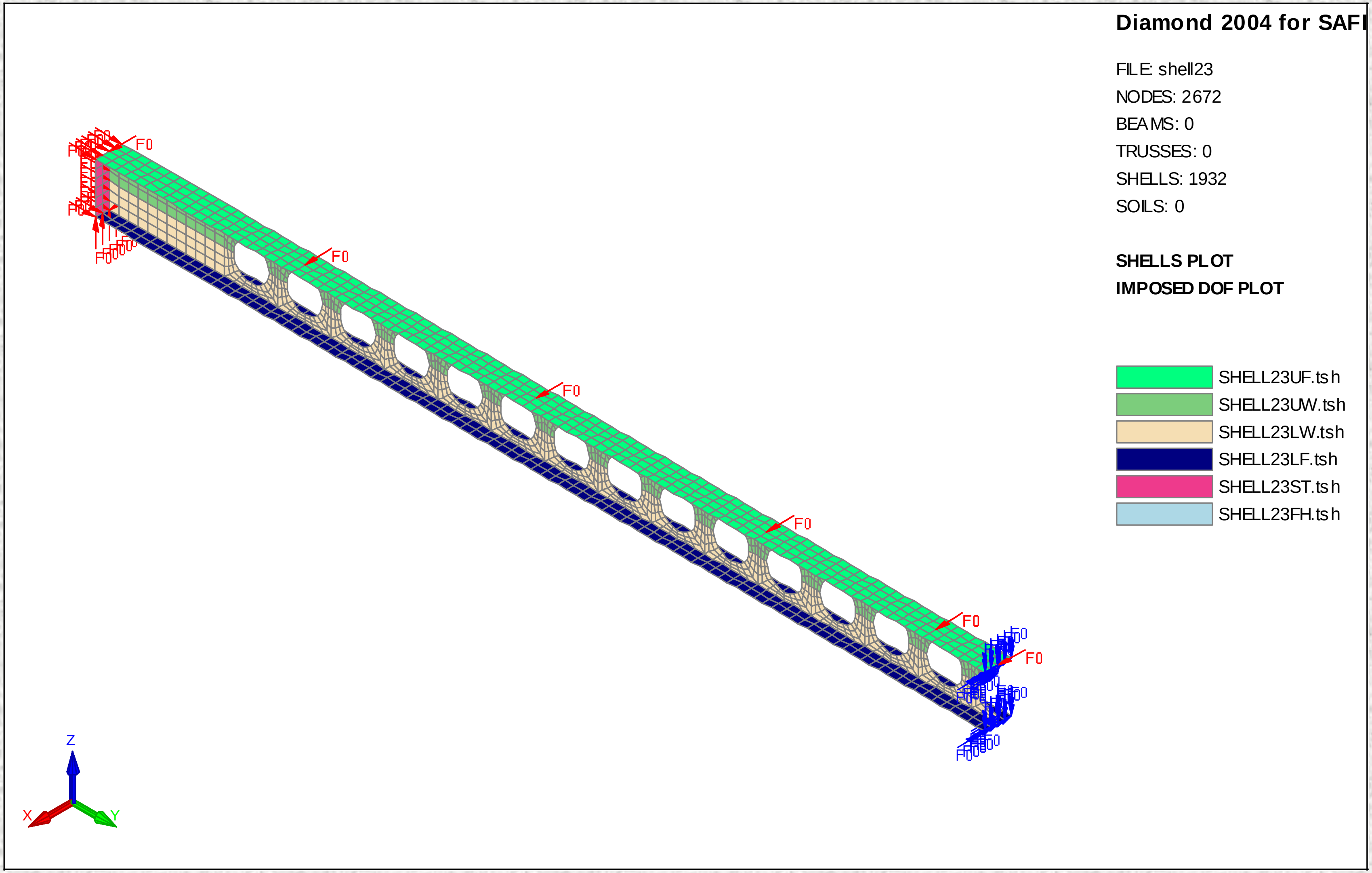
Case study 7 : Composite Steel-Concrete bridge subjected to a local fire

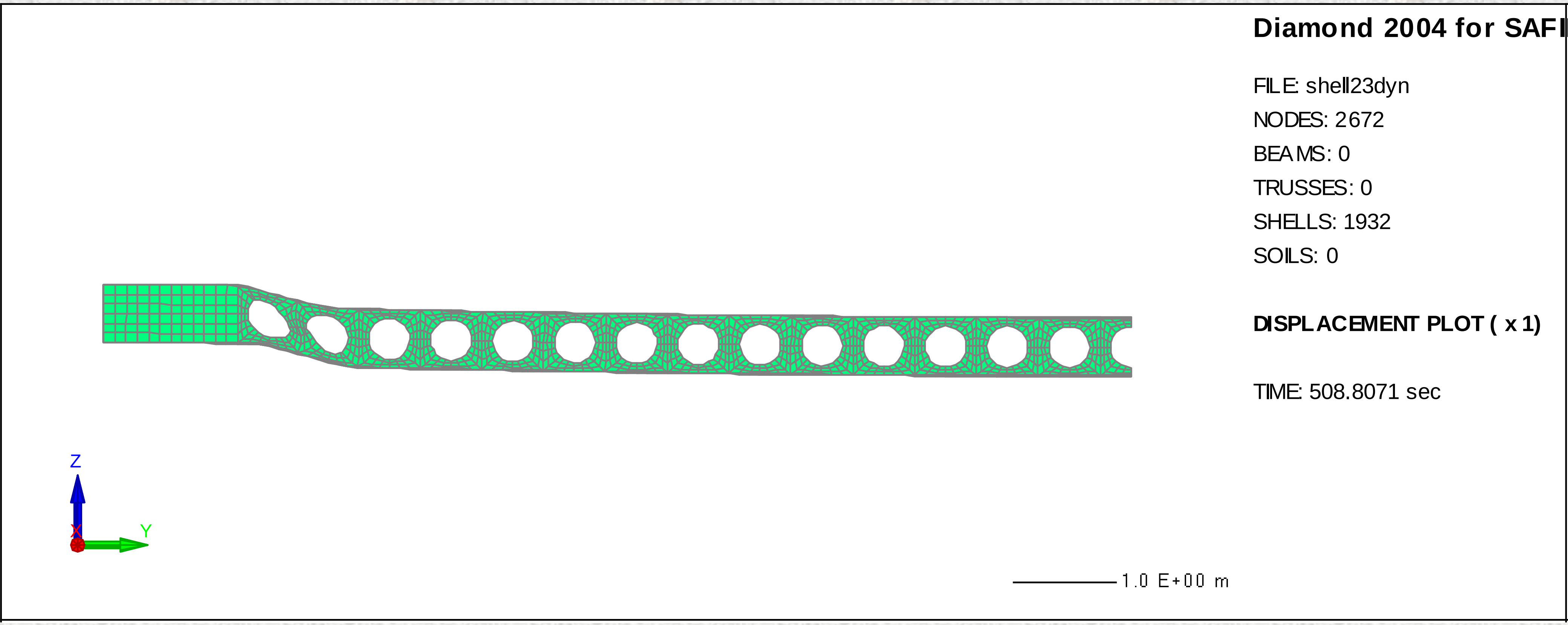


Case study 8 : Lee’s Frame Analysed with Shell F.E.
dT/dt = 1°C/s

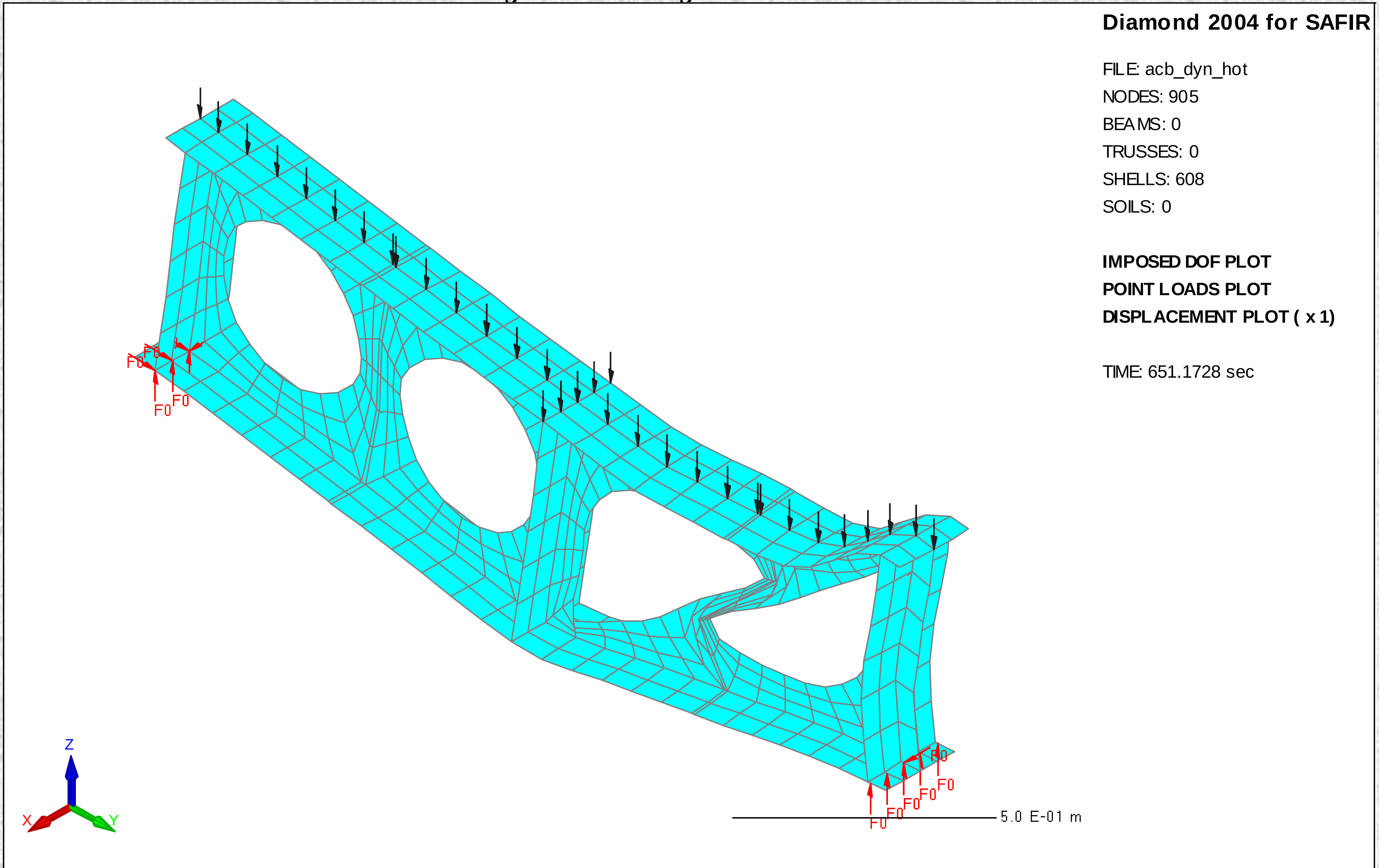


Case study 8 : Cellular Steel beam

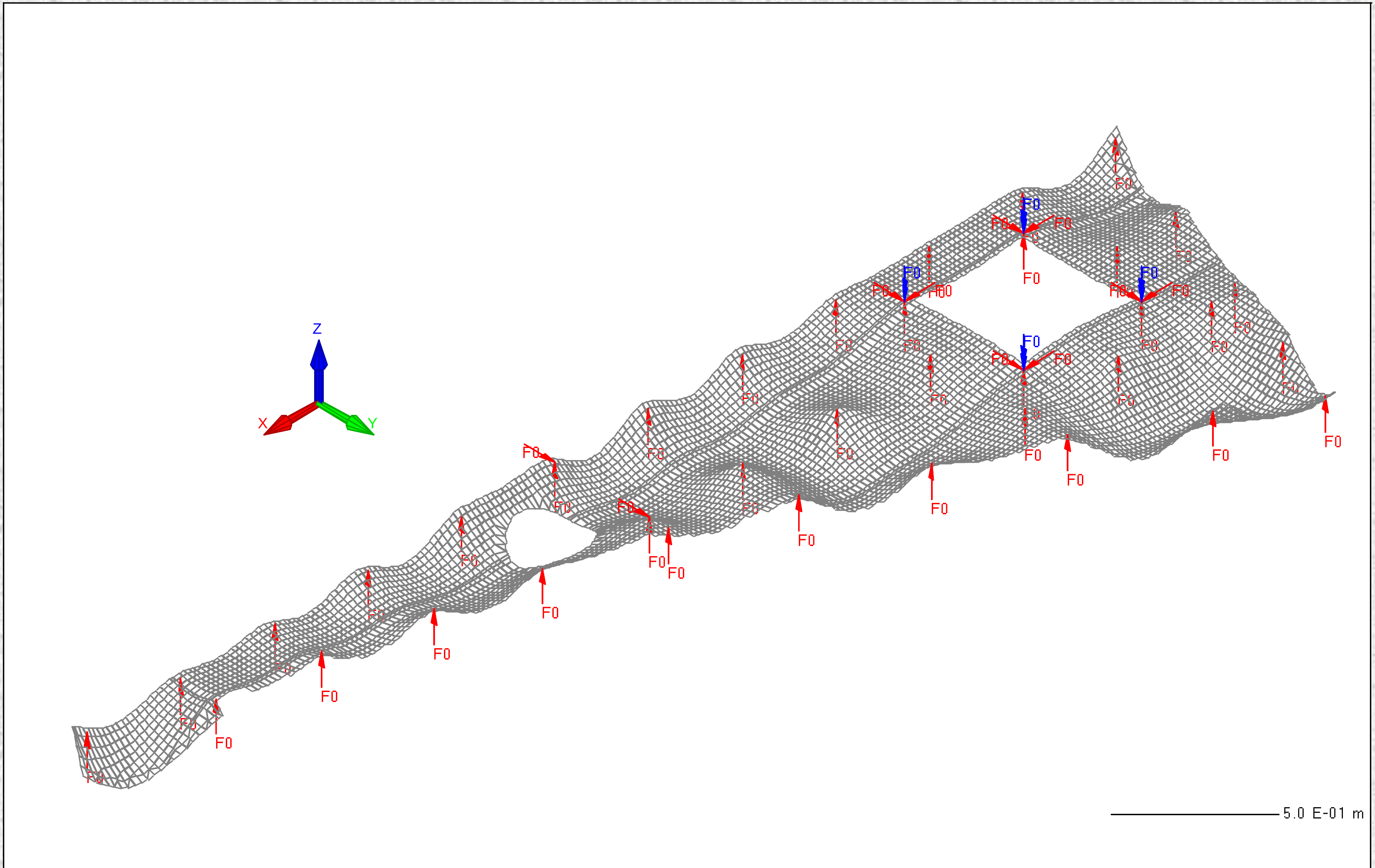



Diamond 2004 for SAFI
FILE: shell23dyn
NODES: 2672
BEAMS: 0
TRUSSES: 0
SHELLS: 1932
SOILS: 0
DISPLACEMENT PLOT (x 1)
TIME: 508.8071 sec
Z
X
Y
1.0 E+00 m

Case study 9 : Short Cellular Steel beam
Symmetry not used



Case study 9 : Reinforced concrete flat slab (20°C)



Dynamic mode:

- ✓ is reasonably CPU expensive,
- ✓ solves local instabilities caused by unstable material models,
- ✓ solves local instabilities caused by geometrical effects,
- ✓ gives a much better insight in failure modes.

How to do it in SAFIR?

• Add masses (in kg).

Which masses ?

Note: there is no gravity in SAFIR. As a consequence, if there is a gravity load of F, you should probably introduce a mass of F/9,81.

⇒ Mass corresponding to the self weight of the structure.

⇒ Mass corresponding the implied gravity loads.

⇒ Wins loads are normaly not associated to a mass.

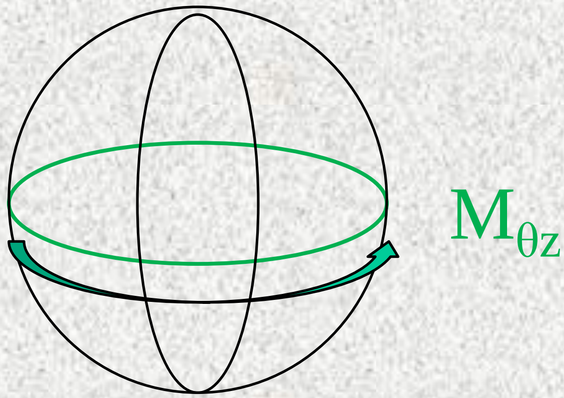
Mass on a node: M_x M_y M_z $M_{\theta x}$ $M_{\theta y}$ $M_{\theta z}$

X, Y, Z are the axes of the global SoC.

Translation masses: most of the times $M_x = M_y = M_z$

(for a ball on a table, you may have $M_x = M_y = 0$ and $M_z \neq 0$)

Rotational masses: $M_{\theta x} \neq M_{\theta y} \neq M_{\theta z}$

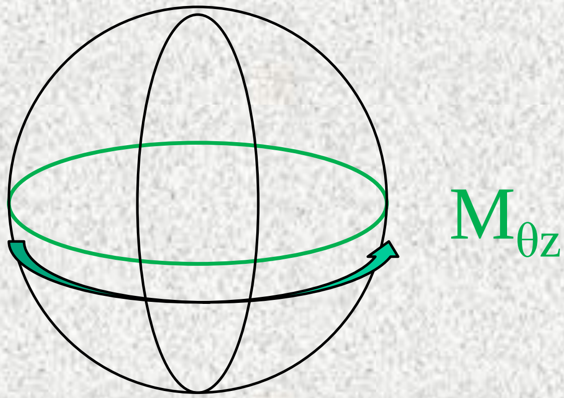


Distributed mass on a beam: $M_{translation}$ $M_{rotation}$

Translation mass: $M_{translation}$ in kg/m

Rotational masses

Not relevant for rotation around axes that are



You may increase the mass artificialy to facilitate convergence (mass scaling).This is because the purpose of the dynamic analysis in SAFIR is not to predict exactly the time needed for a particular member to evolve from a stable position to a collapsed position (by buckling, for example, which my last for less than 1 second). The purpose is to facilitate the convergence during this process.

The masses are active only when the accelerations are significant.

- Use a (very) small value for the COMEBACK

Take care !

If the struture is a mechanism, SAFIR will run.

If there is no support at all, the structure will accelerate down at 9,81 m/s² (and you will not see it anymore in Diamond).

System with 4 bars (= mechanism).

Position chosen to be in equilibrium if the 3 forces are equal.

Loads of 30, 20 et 10 kN applied in 20 seconds