SECURE WITH STEEL
Esch, November 5, 2015

New features in SAFIR® 2016

Jean-Marc Franssen
Thomas Gernay

1) 3D brick finite elements
2) Local buckling in steel beam finite elements
3) Negative terms on the main diagonal
4) New laws for reinforcing steel
5) New PRNSTRAIN command
6) Spring finite element
7) Orientation of the re-bars in shell finite elements
8) LOCAFI fires
9) New DIAMOND

1) 3D brick finite elements

Currently: brick linear elements with 6 or 8 nodes

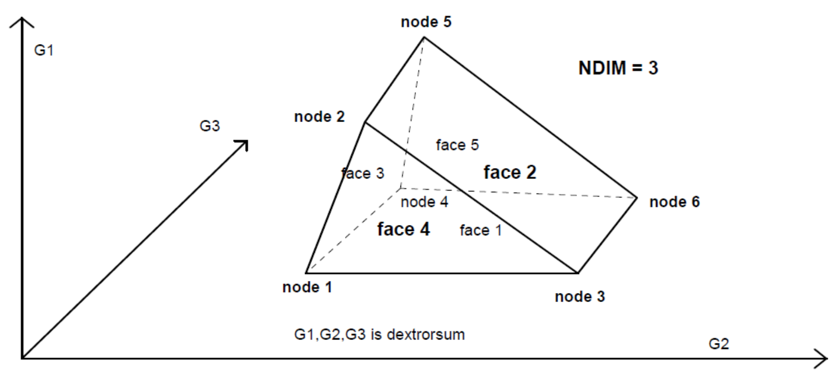


Figure 19: nodes and faces of elements with 6 nodes for 3D analyses

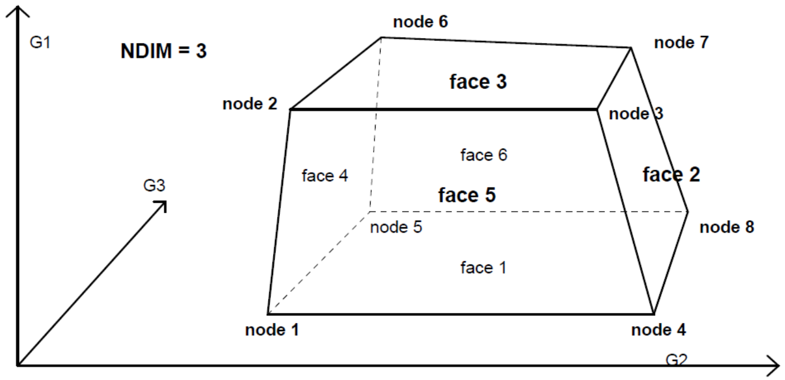
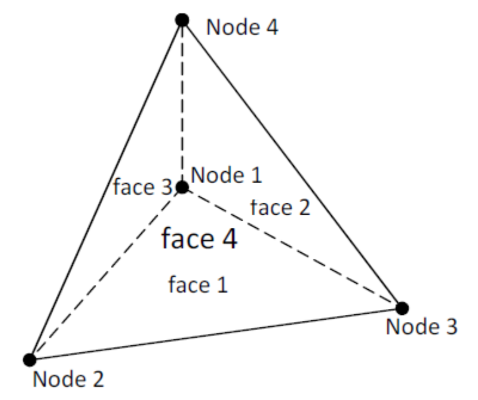


Figure 20: nodes and faces of elements with 8 nodes for 3D analyses

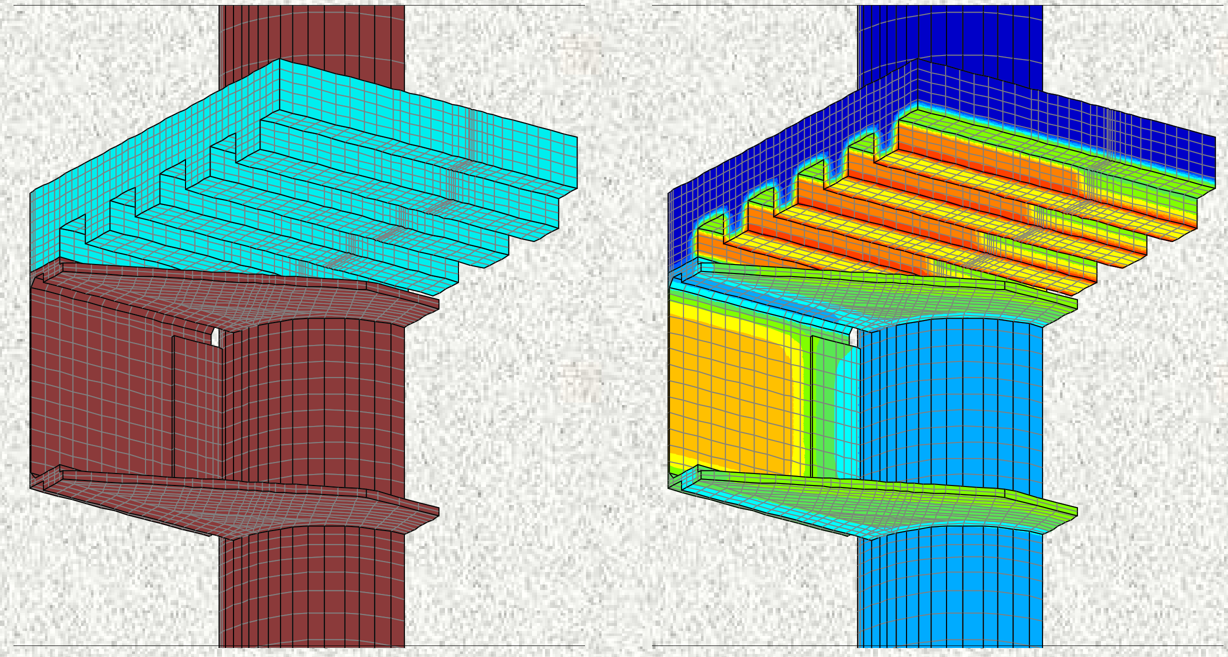
Future: tetrahedra



Thermal analysis

Materials: Concrete – Steel – Wood
– Gypsum – Aluminum – User

3D thermal calculation
Steel-concrete joint
31 502 nodes
25 411 solid elements



Mechanical analysis

Capabilities

-Materials: Concrete and steel

-Fully multiaxial stress states

-Ambient and elevated temperature

Assumptions and limitations

-Static calculations

-Large displacements not taken into account

-No spalling in concrete

-Smeared crack model for concrete

Mechanical analysis

Concrete model

-Plastic-damage model

-Drucker Prager – Rankine

-Eurocode

-Crack closure effect

-Explicit transient creep

Steel model

- Plastic model
- Von Mises
- Eurocode

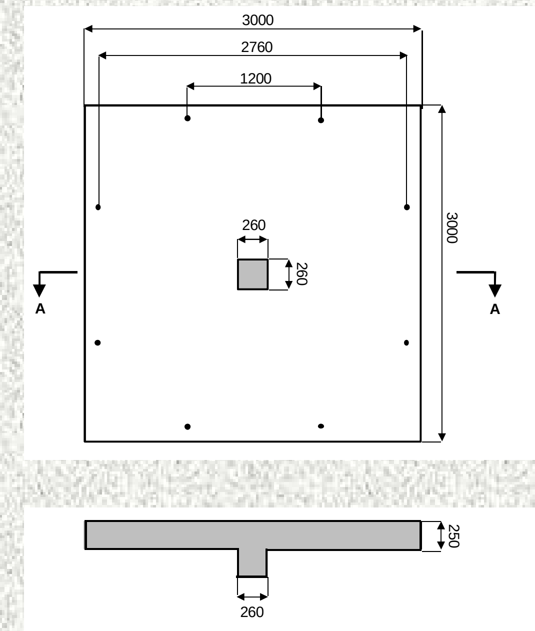
Gernay, T., & Franssen, J.-M. (2015). A plastic-damage model for concrete in fire: Applications in structural fire engineering. Fire Safety Journal, 71, 268–278. http://hdl.handle.net/2268/175163

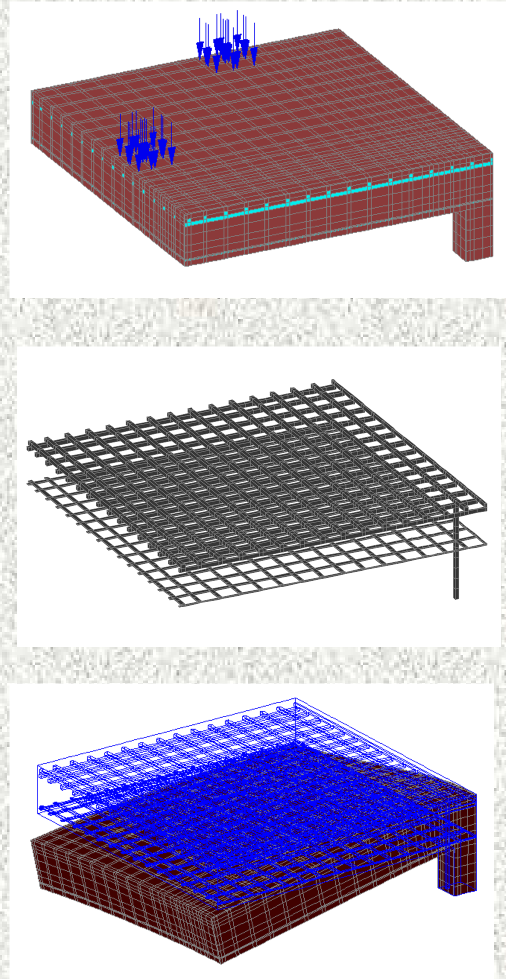
Gernay, T., Millard, A., & Franssen, J.-M. (2013). A multiaxial constitutive model for concrete in the fire situation: Theoretical formulation. International Journal of Solids and Structures, 50(22-23), 3659-3673. http://hdl.handle.net/2268/153663

Gernay, T., & Franssen, J.-M. (2012). A formulation of the Eurocode 2 concrete model at elevated temperature that includes an explicit term for transient creep. Fire Safety Journal, 51, 1-9. http://hdl.handle.net/2268/114050

Mechanical analysis

Example: shear punching in flat slab
Ambient temperature (EPFL 2006)





Mechanical analysis

Examples of possible applications:

Concrete:
- Shear punching
- Prestressed hollow core slabs
- Concrete masses (e.g. in nuclear applications)

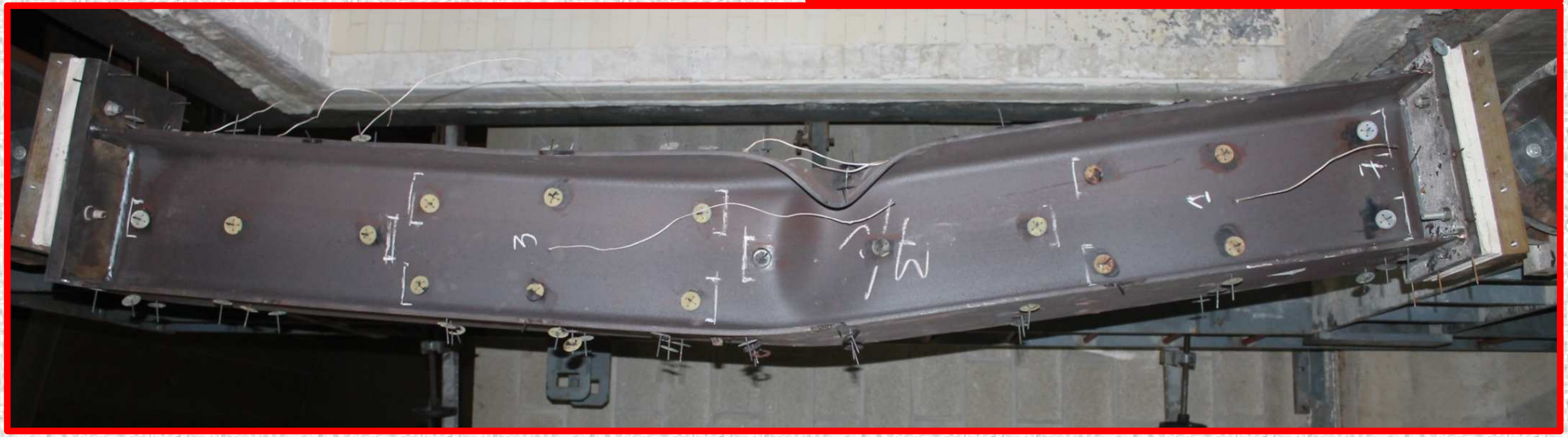
Steel:
- Flame straightening of heavy sections

Concrete & Steel
- Joints

Main limitation
- No contact element

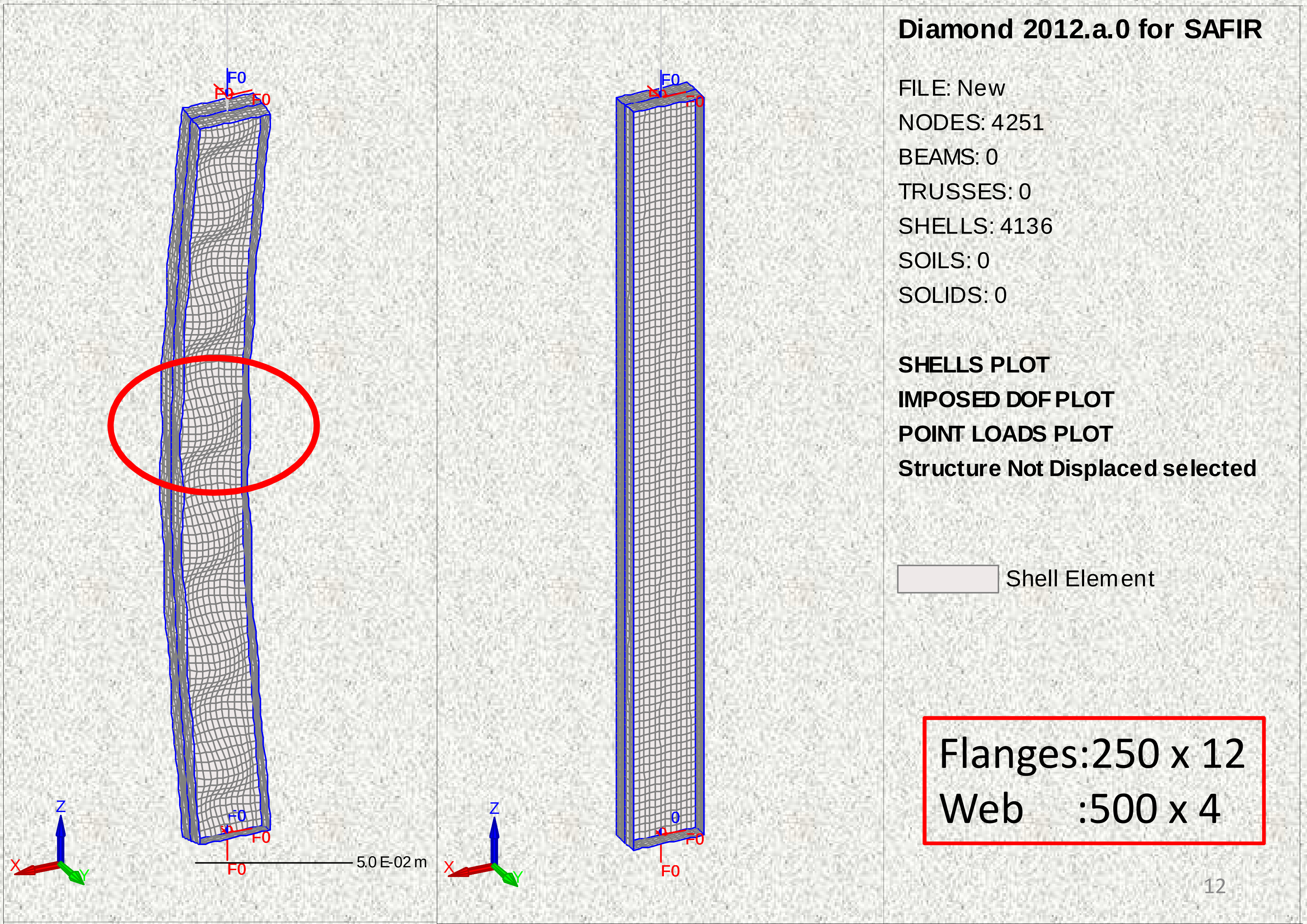
2) Local buckling in beam finite elements

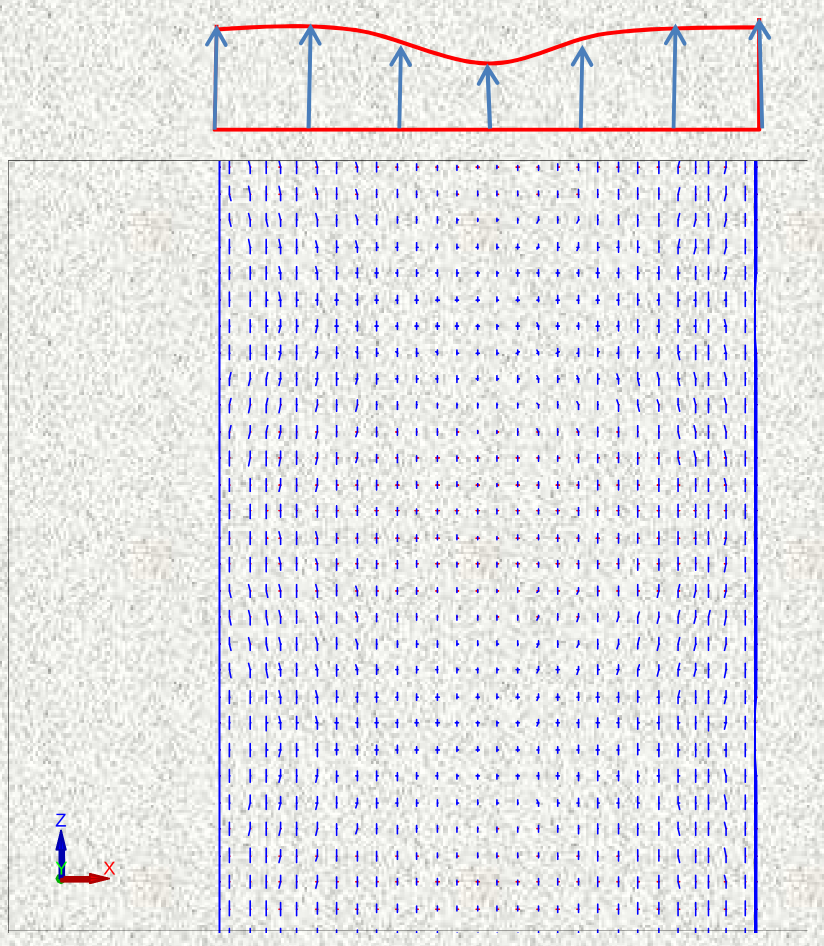
Steel sections made of slender plates may deform locally (local buckling)



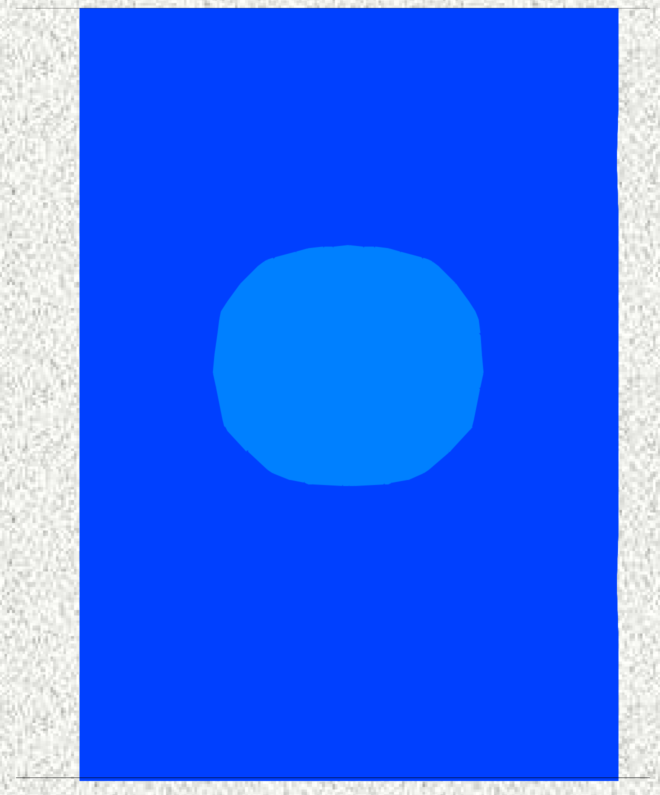
=> They cannot be modelled with beam finite elements

Why can’t they?

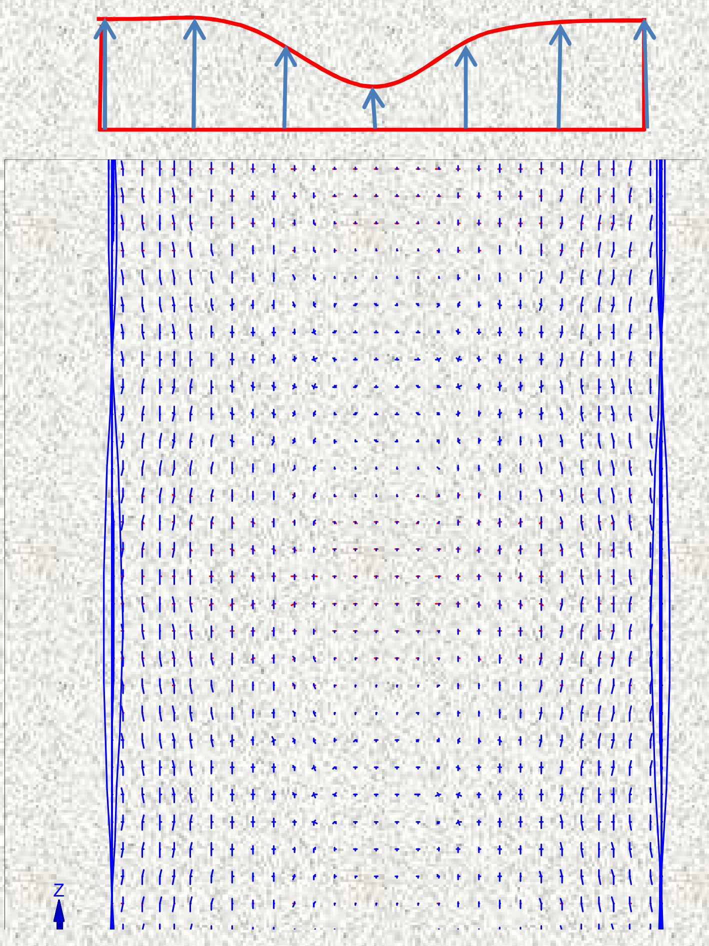




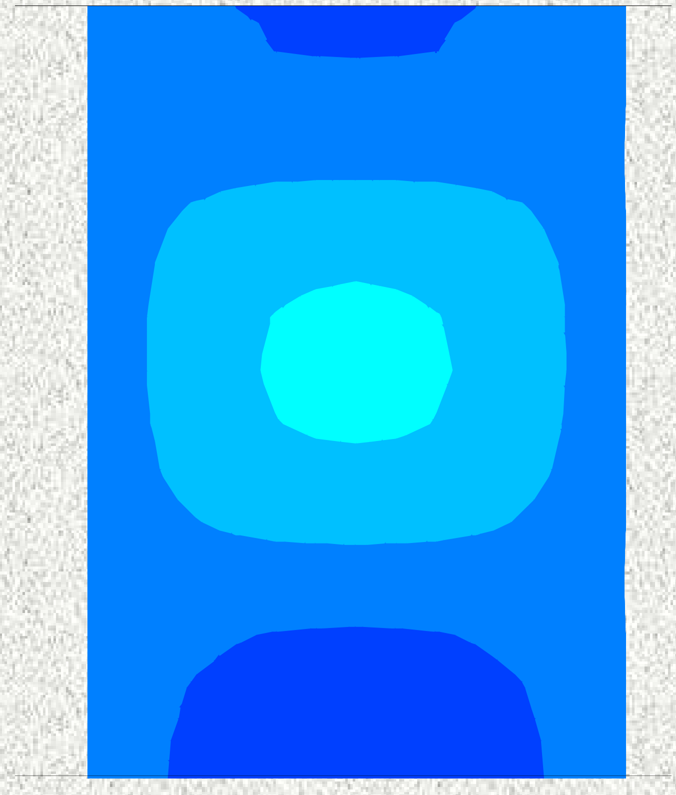
Membrane forces
In the web



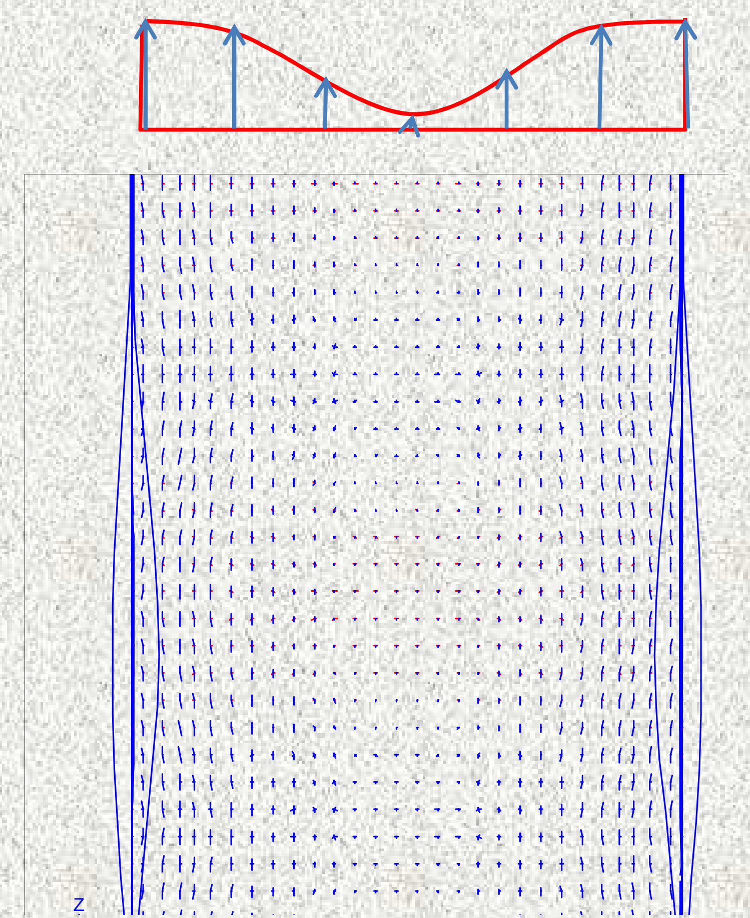
Perpendicular displacement
In the web



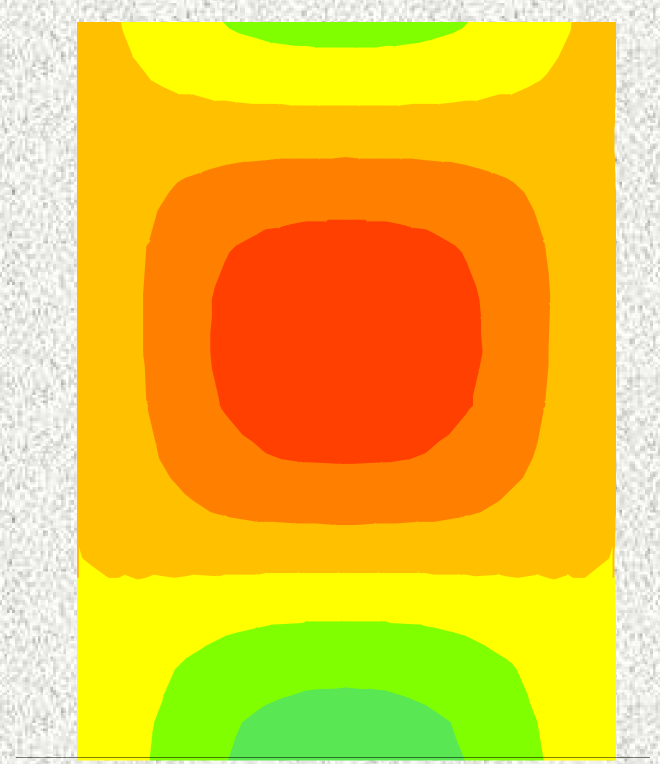
Membrane forces
In the web



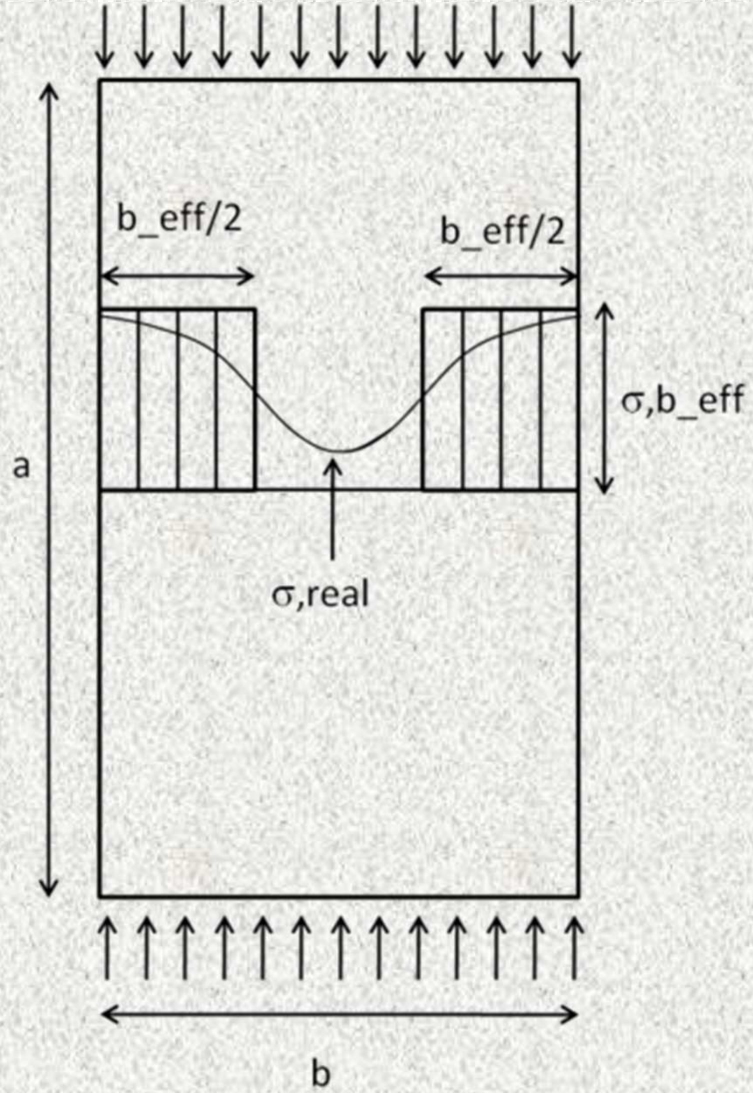
Perpendicular displacement
In the web



Membrane forces
In the web



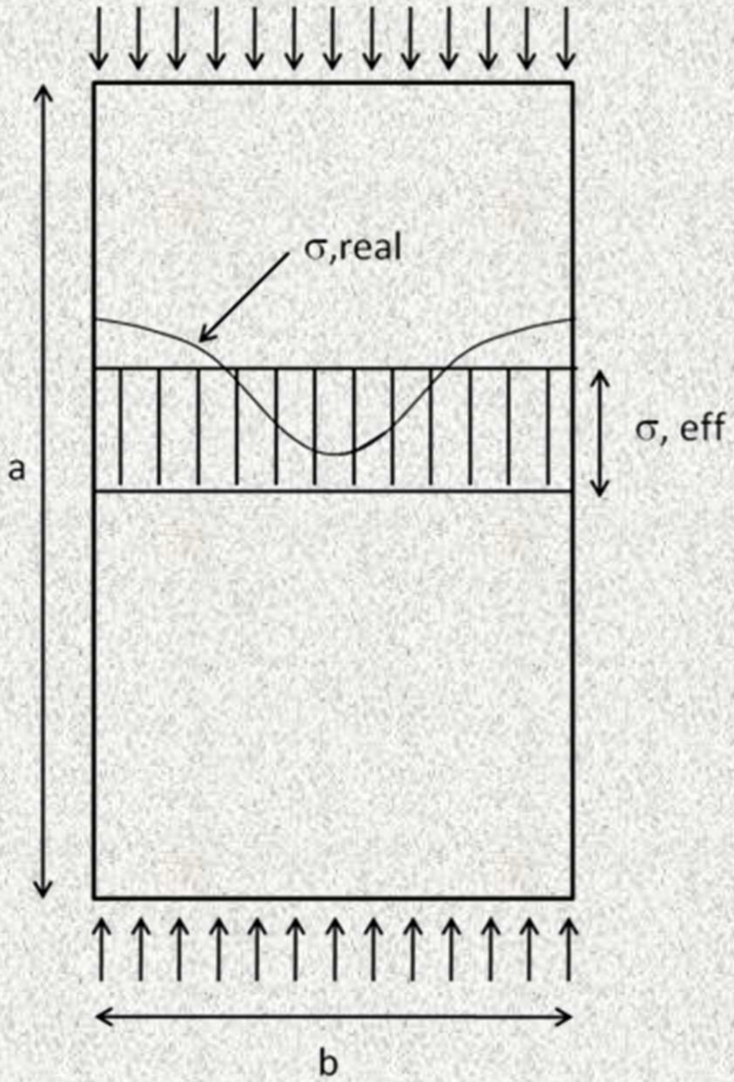
Perpendicular displacement
In the web



Effective width: b_{eff}

$b_{eff} = f(\sigma_{max})$ $\sigma_{max} = f(b_{eff})$

If used in F.E, it must be introduced **at the element level**

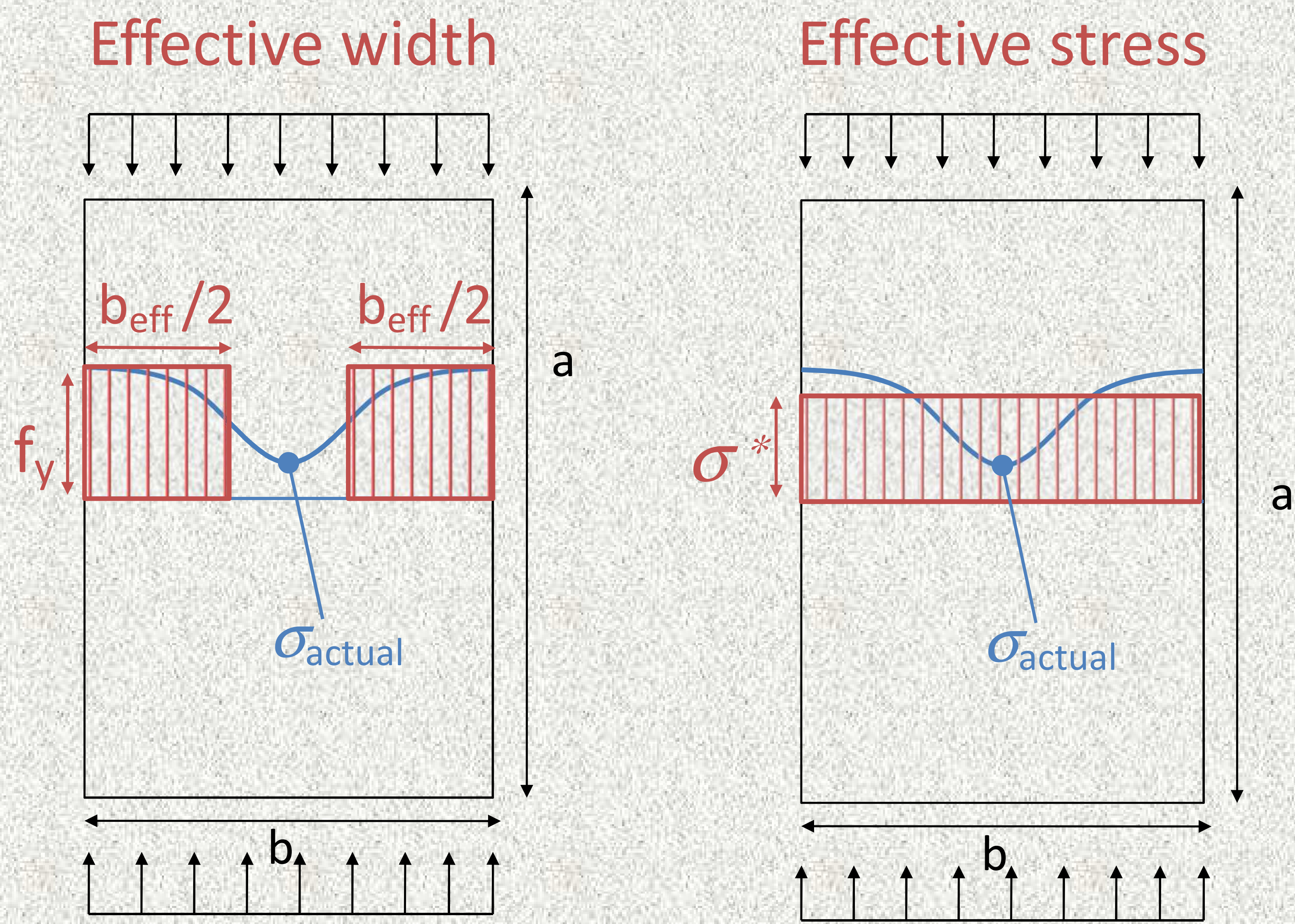


Effective stress: σ_{eff}

$\sigma_{eff} = f(\varepsilon)|_{\text{support conditions, slenderness, temperature}}$

If used in F.E, it can be introduced **at the material level**

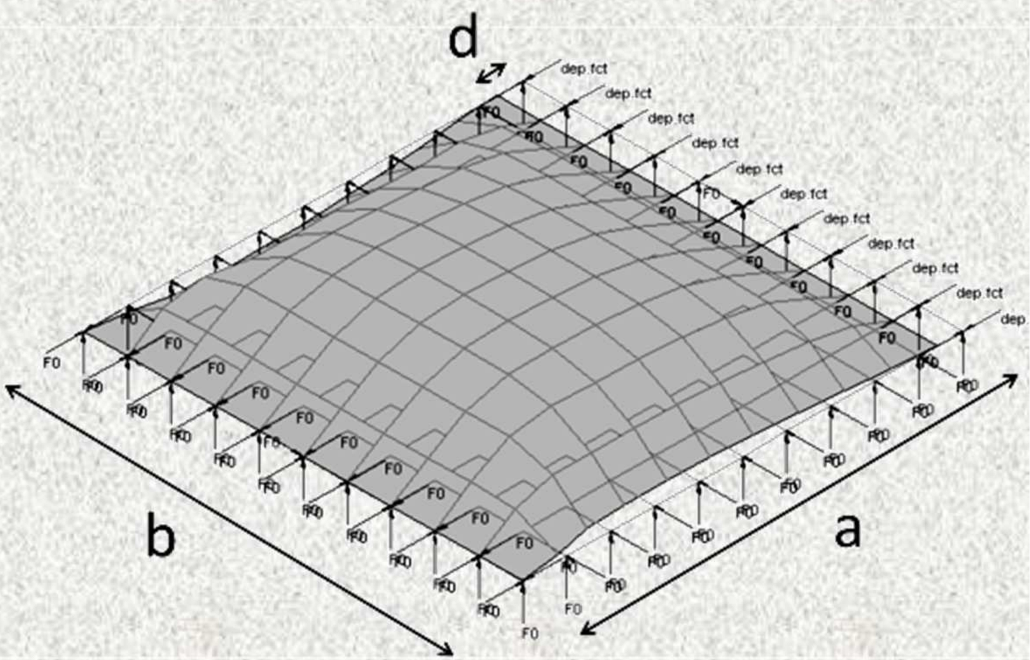
New proposal: Effective stress

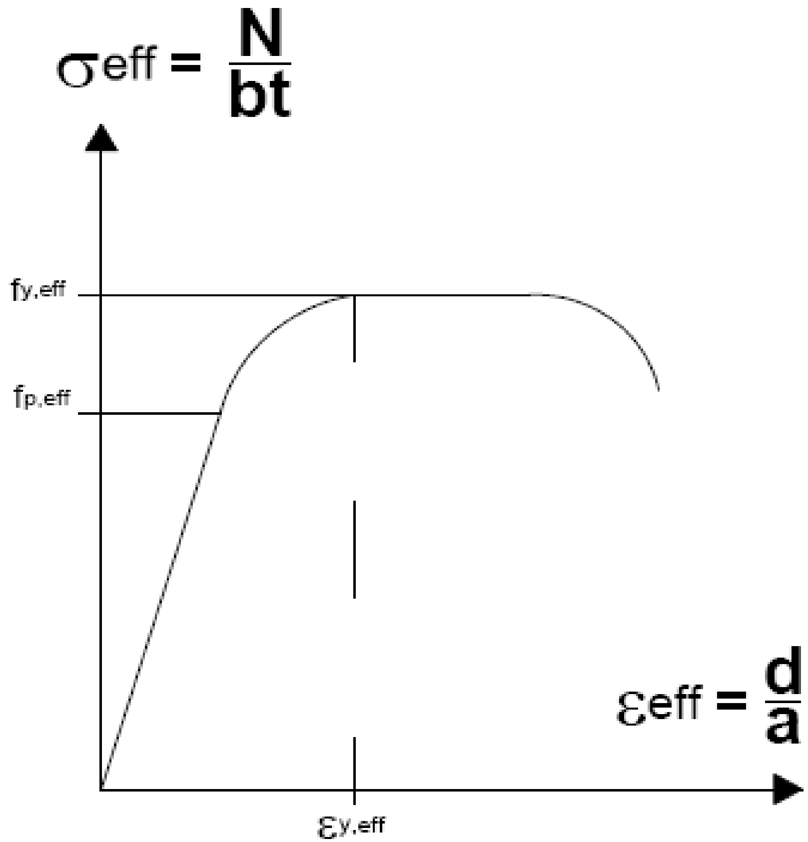


How do we determine $\sigma_{eff} = f(\varepsilon)$?

By a series of numerical push-over tests made for different:

- Support conditions
- Plate slendernes
- Temperatures

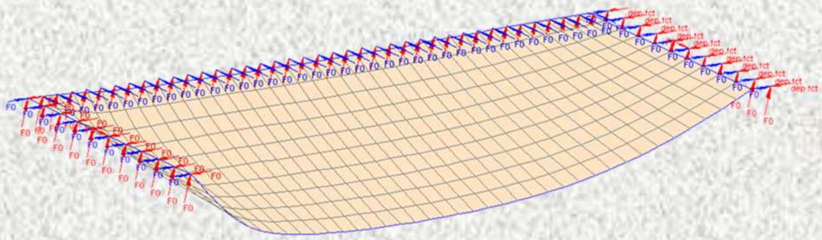




Various support conditions

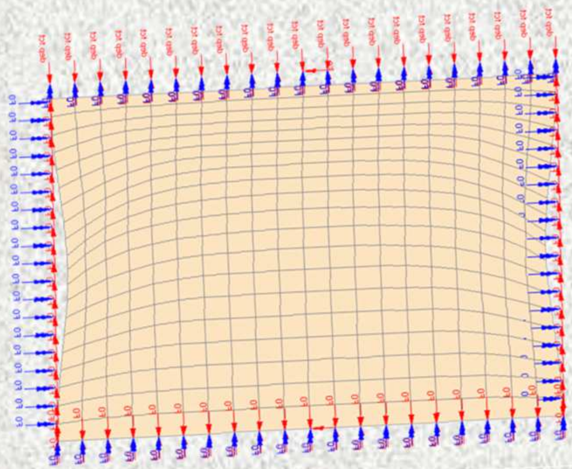
Flange

Simply supported
on 3 sides



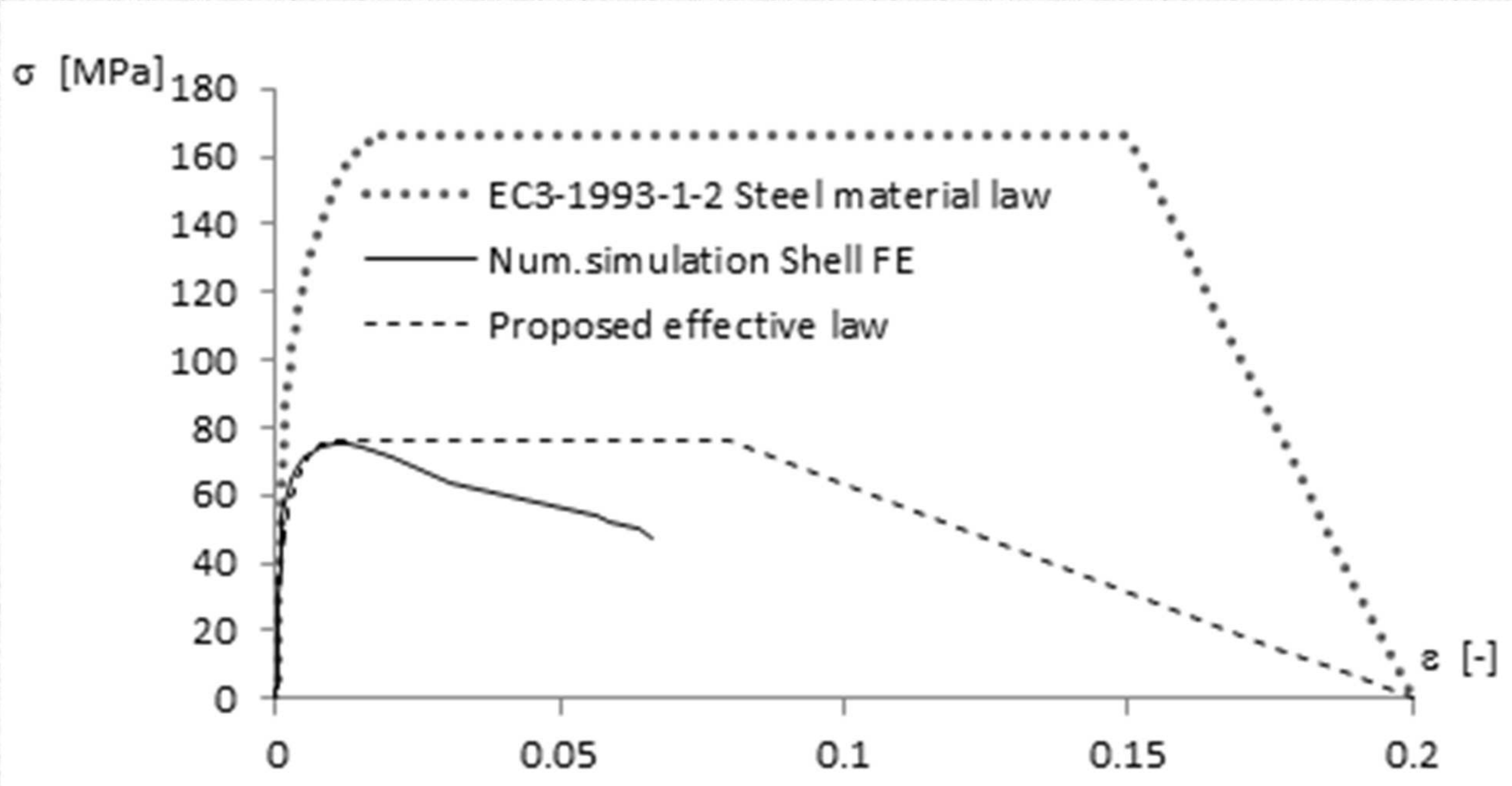
Web

Simply supported
on 4 sides

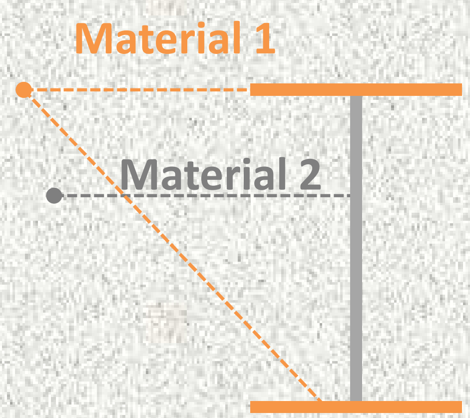


The stress-strain relationship is the one of Eurocode 3.

For each combinaison of Temperature – Slenderness - support condition, the values of $f_{p,eff}$ and $f_{y,eff}$ in compression are modified in the material law (E and ε_u remain unchanged, as well as all parameters in tension)

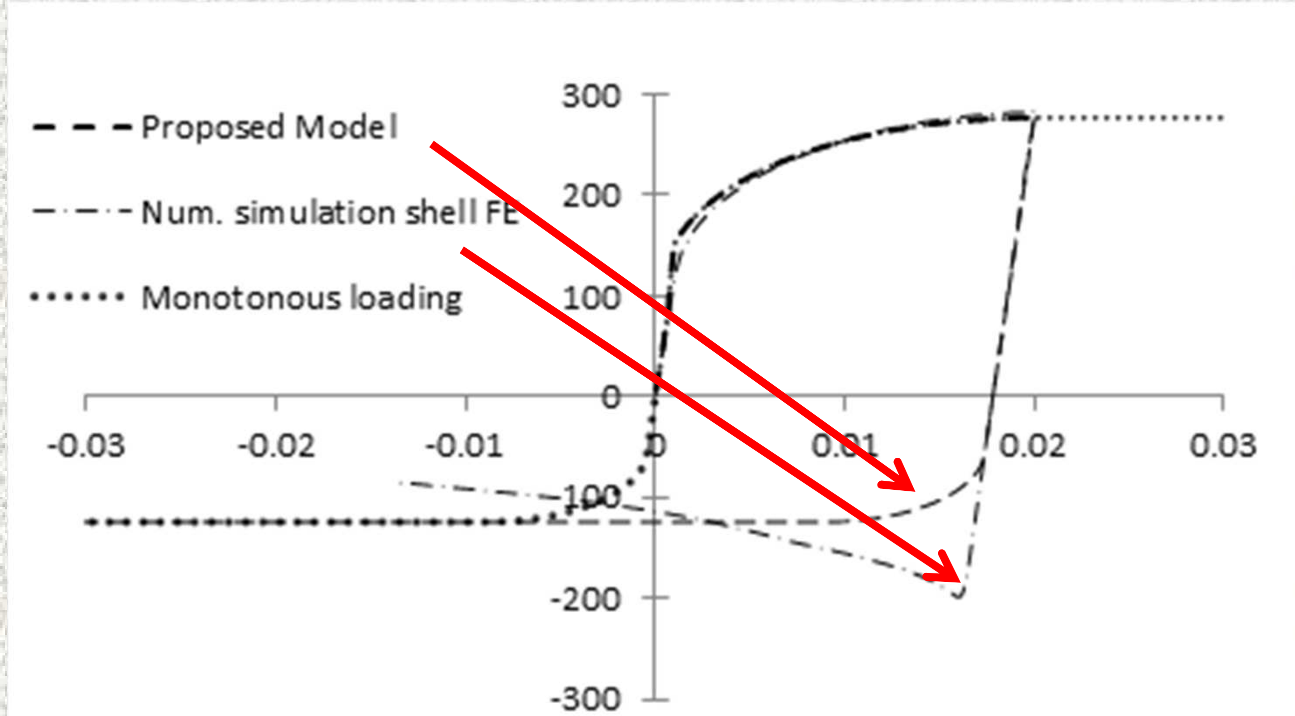


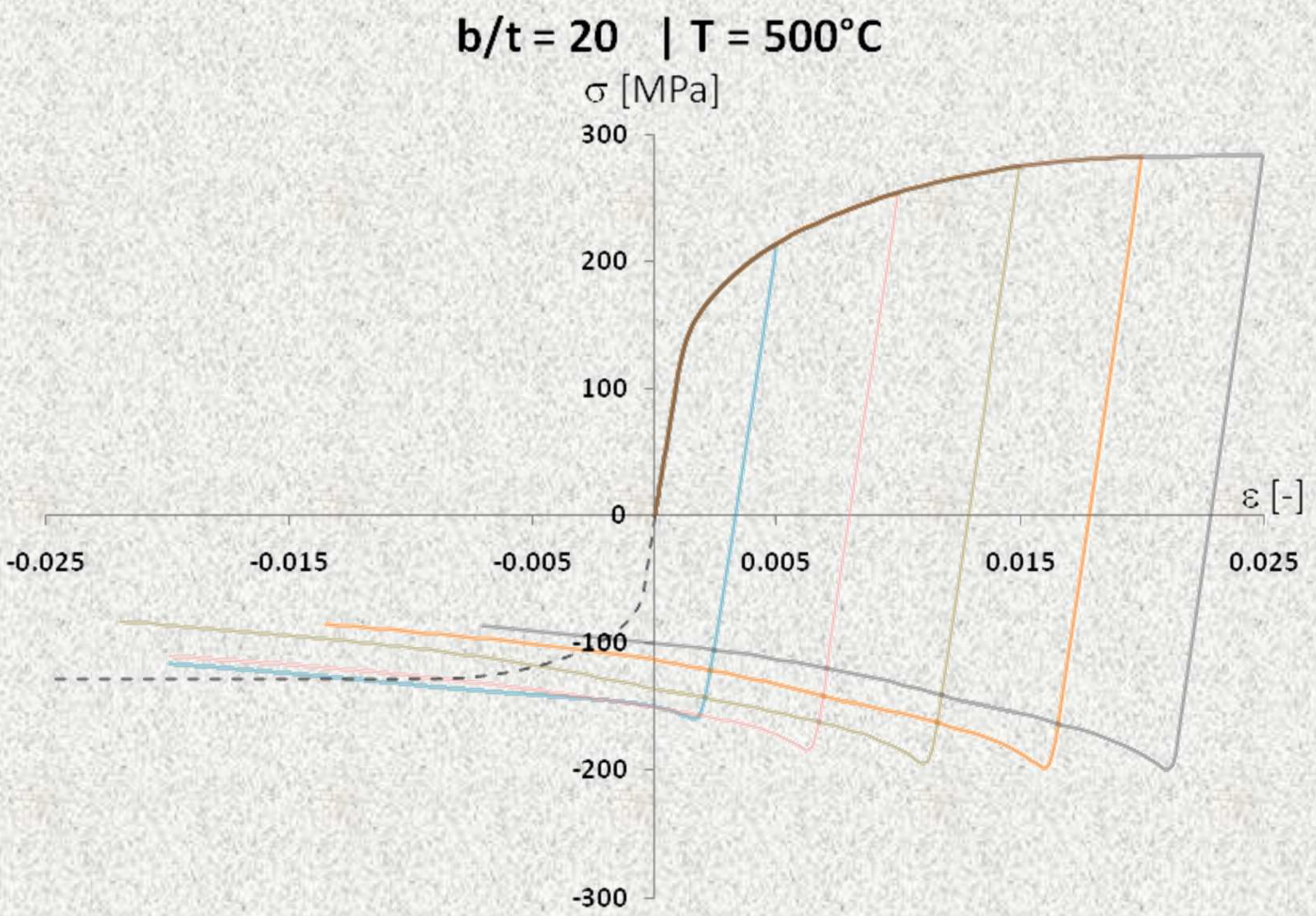
The user gives in the input file f_y, b/t and the support condition for the web and the flange



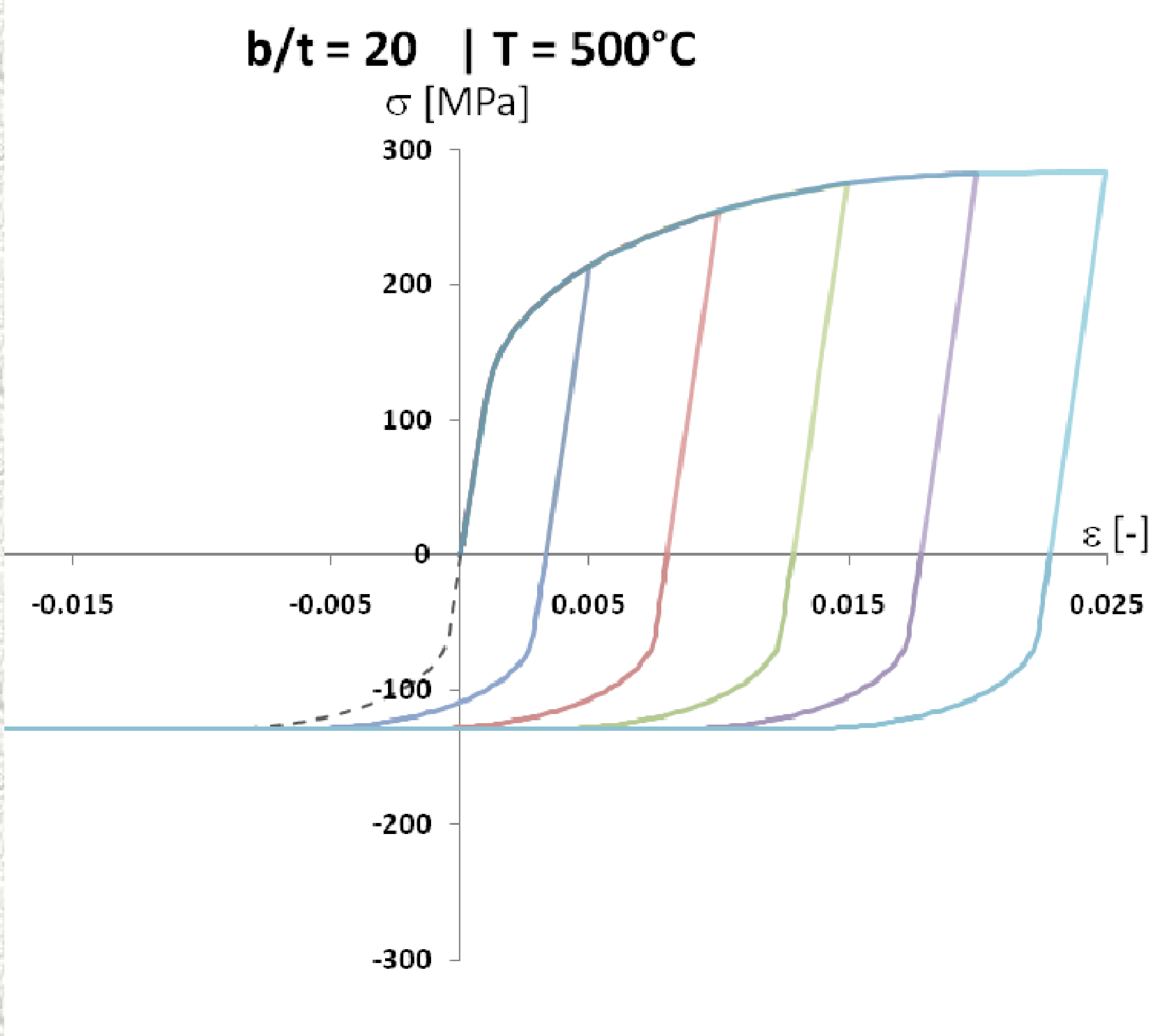
In the members, every point of integration follows its own σ_{eff}-ε relationship

Stress strain relationship in tension => compression



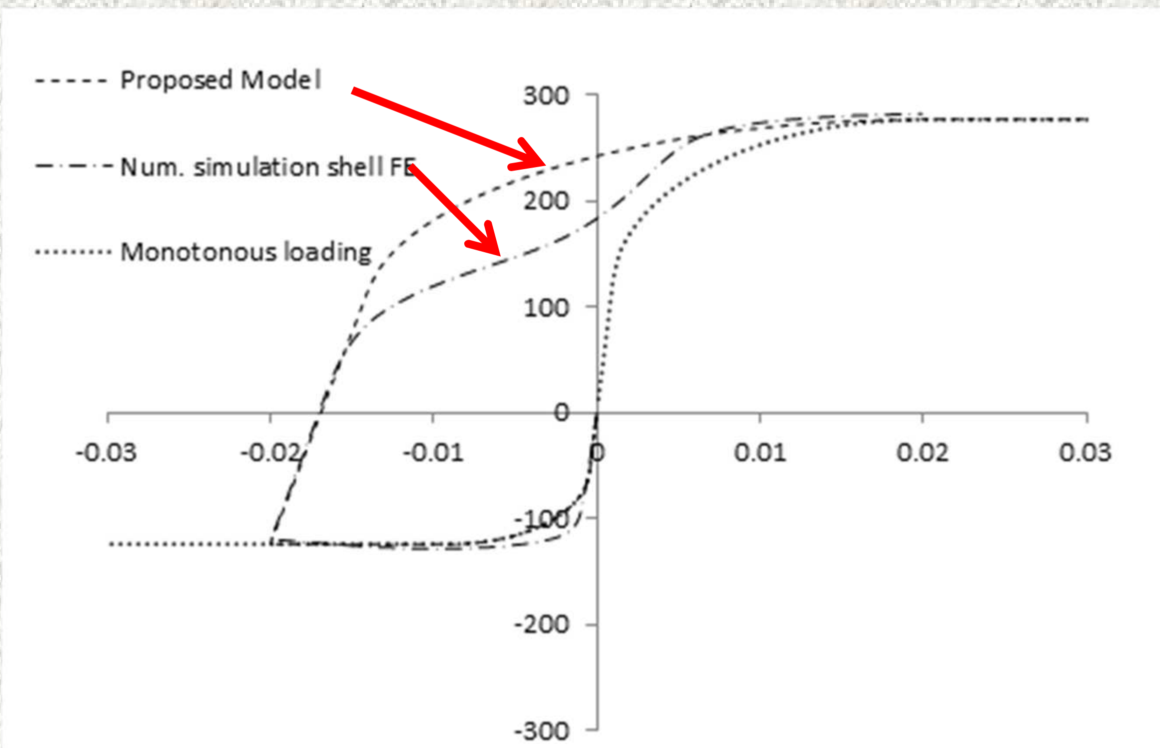


Simulations with shell finite elements



Material model used in beam finite elements

Stress strain relationship in compression => tension



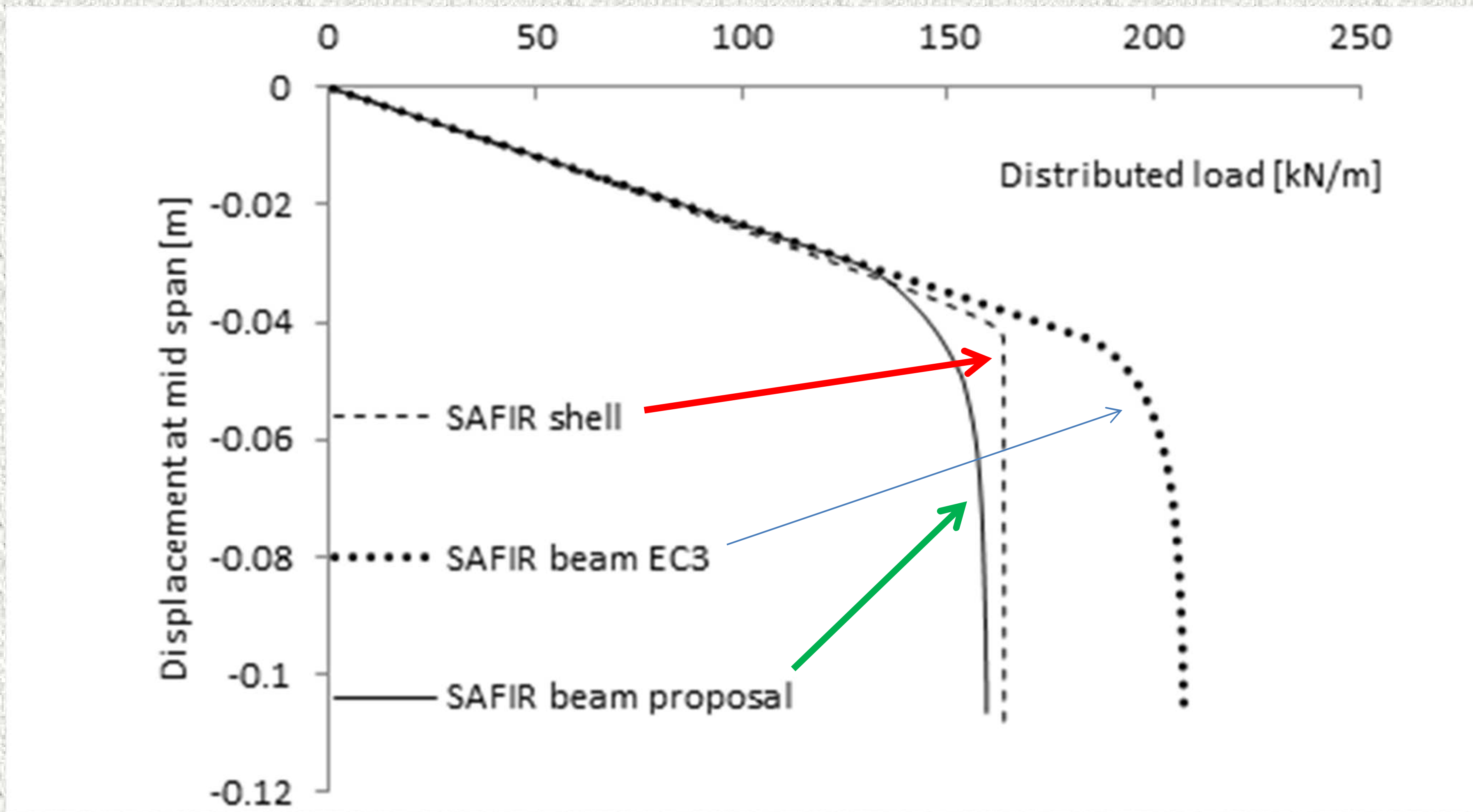
VALIDATIONS AGAINST SHELL F.E.

Simply suported beam with UDL

L = 6 meters

Section: H = 300x4, B = 150x4

T = 20°C



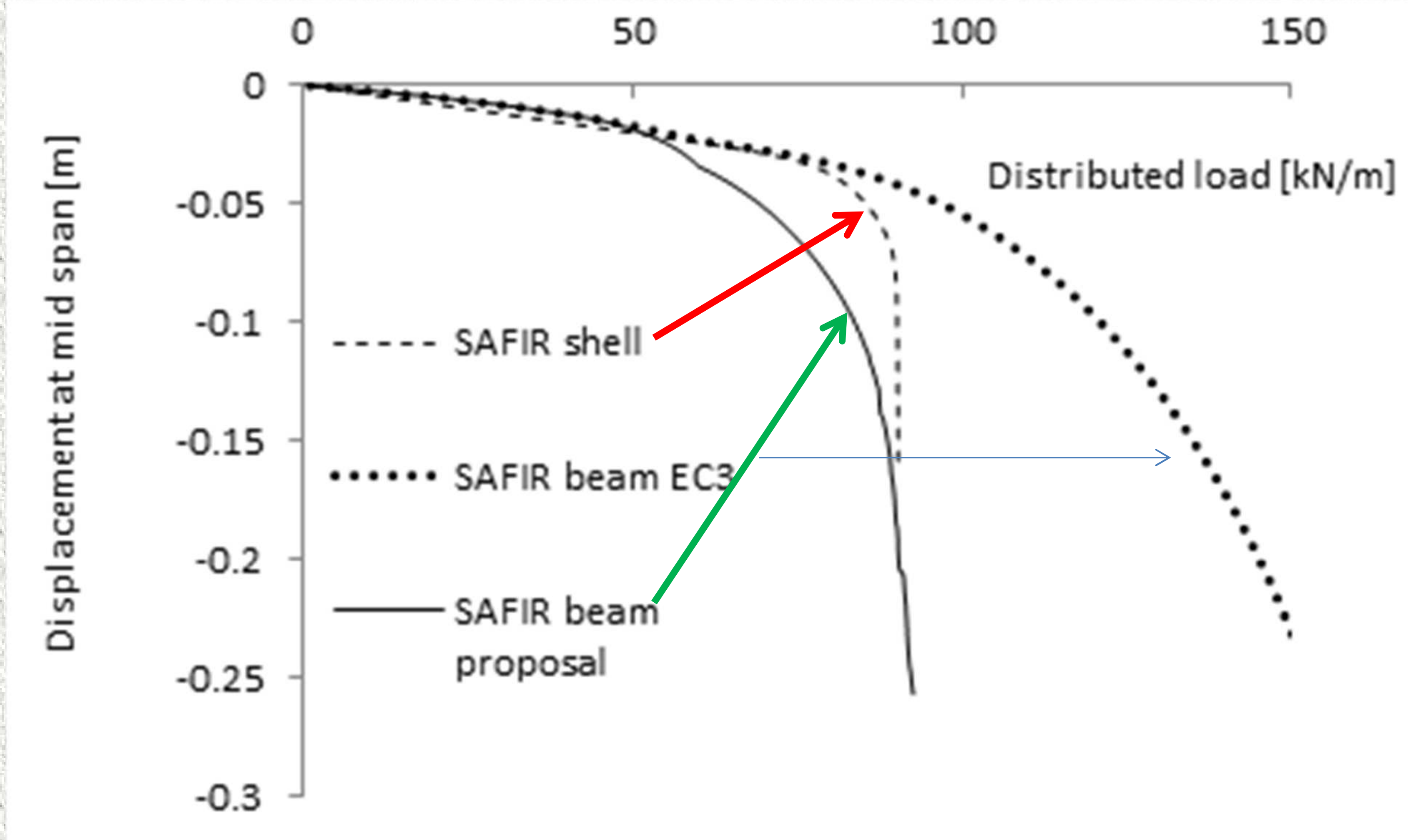
VALIDATIONS AGAINST SHELL F.E.

Simply suported beam with UDL

L = 6 meters

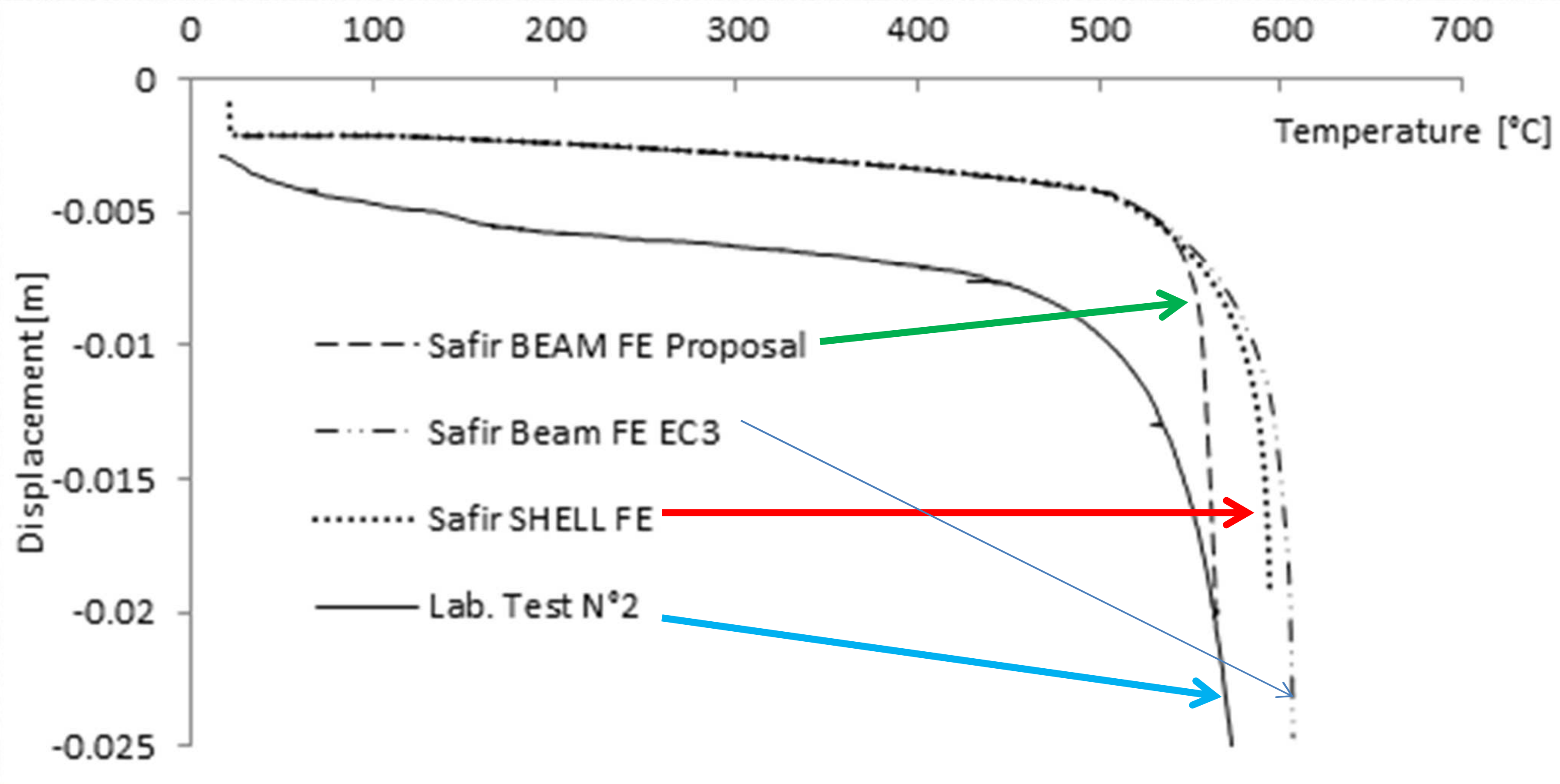
Section: H = 300x4, B = 150x4

T = 500°C



VALIDATIONS AGAINST EXPERIMENTAL TESTS

Simply supported colum N = 122 kN ecc_{weak} = 5 mm
H = 2,7 meters
Section: H = 450x4, B = 150x5

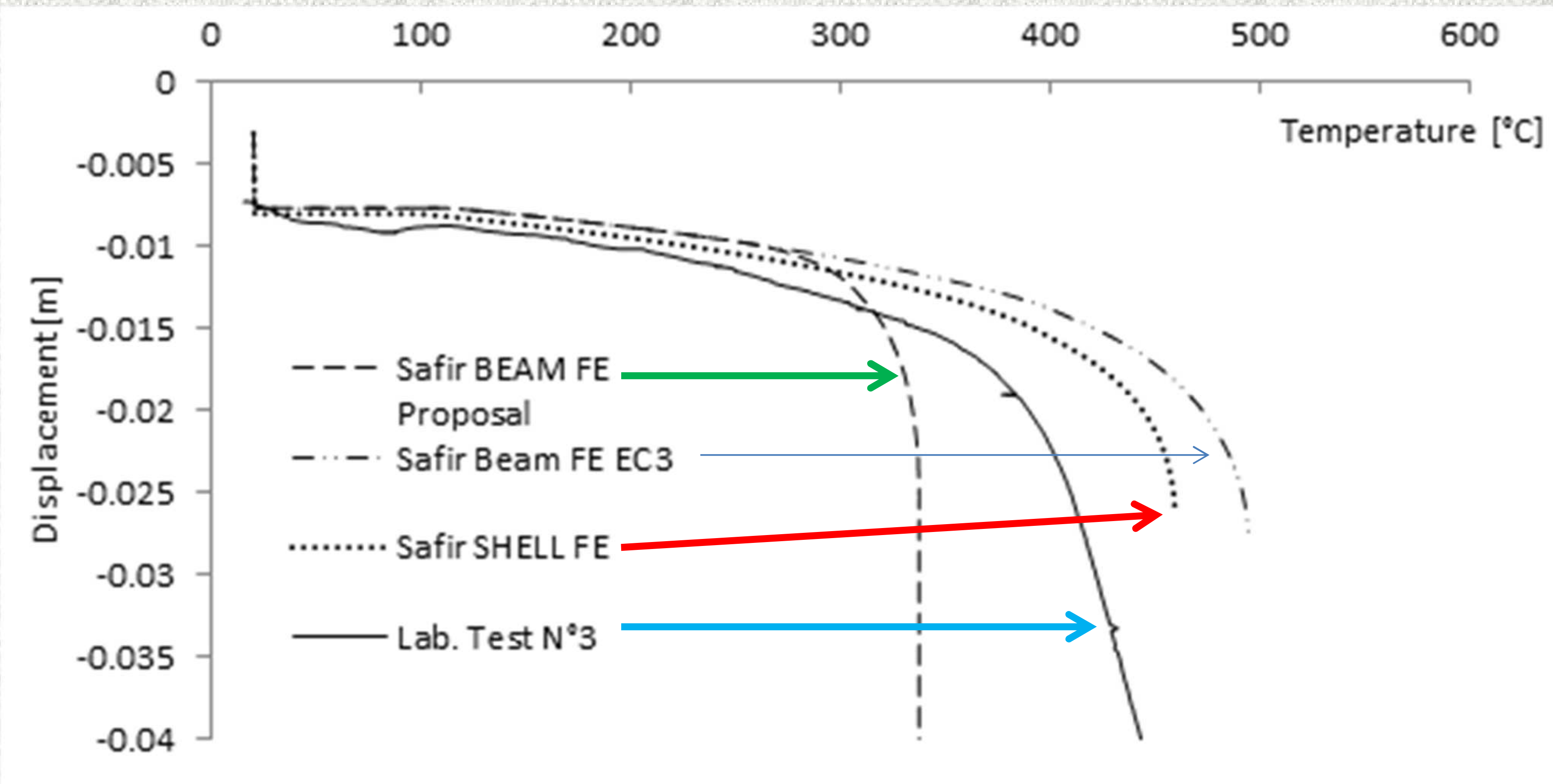


VALIDATIONS AGAINST EXPERIMENTAL TESTS

Simply supported colum N = 204 kN ecc_{weak} = 4-13 mm

H = 2,7 meters

Section: H = 450x4, B = 150x5

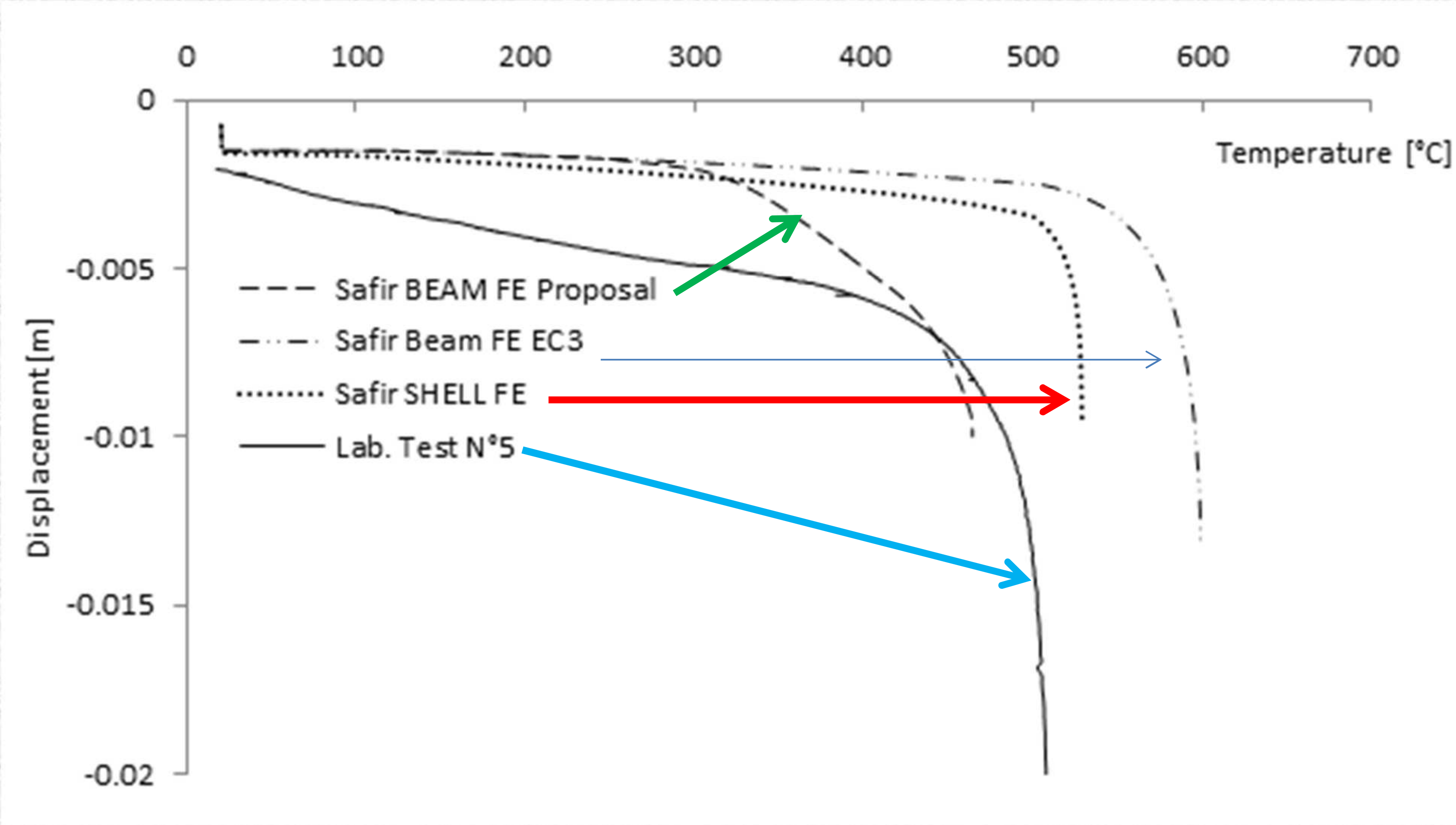


VALIDATIONS AGAINST EXPERIMENTAL TESTS

Simply supported colum N = 231 kN ecc_{strong} = 71 mm

H = 2,7 meters

Section: H = 360x4, B = 150x5



CONCLUSIONS

- ✓ The proposed technique is extremely CPU efficient compared to shell F.E.
- ✓ It reasonably well accounts for local buckling arising from longitudinal stresses
- ✓ Sometimes too severe

3) Negative terms on the main diagonal

Since version 2014.a.3, a time step is considered as converged even if some negative terms are found on the main diagonal of the stiffness matrix.
With the previous versions, such an occurrence would lead to either a return to the previous time step or to a stop of the run if the minimum value of the time step was reached, with some runs stopping with no obvious physical reason.

4) New laws for reinforcing steel

- ✓ Hot rolled or cold formed bars can be chosen (see Table 3.2a of EN 1992-1-2)
- ✓ Class A, B or C can be chosen (see Figure 3.3 of EN 1992-1-2)

In previous versions, Cold worked, class B or C was used

5) New PRNSTRAIN command

The command

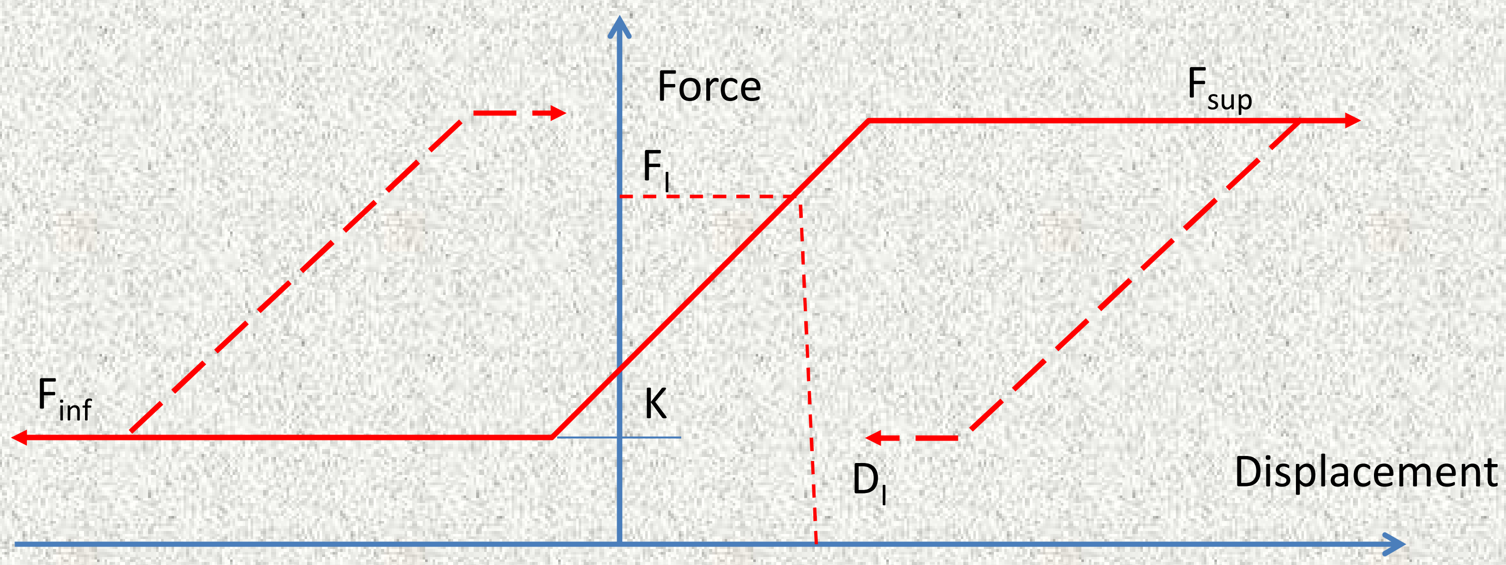
PRNSTRAIN 0.05

will print a message in the output file
when the stress-related strain in a bar of a shell finite element exceeds 5%

6) Spring finite element

This element:

- is attached to one single node (the other virtual extremity of the element is the foundation;
- is characterized by a direction (in 2D or in 3D);
- has a particular « Displacement–Force » behaviour (both in the defined direction)

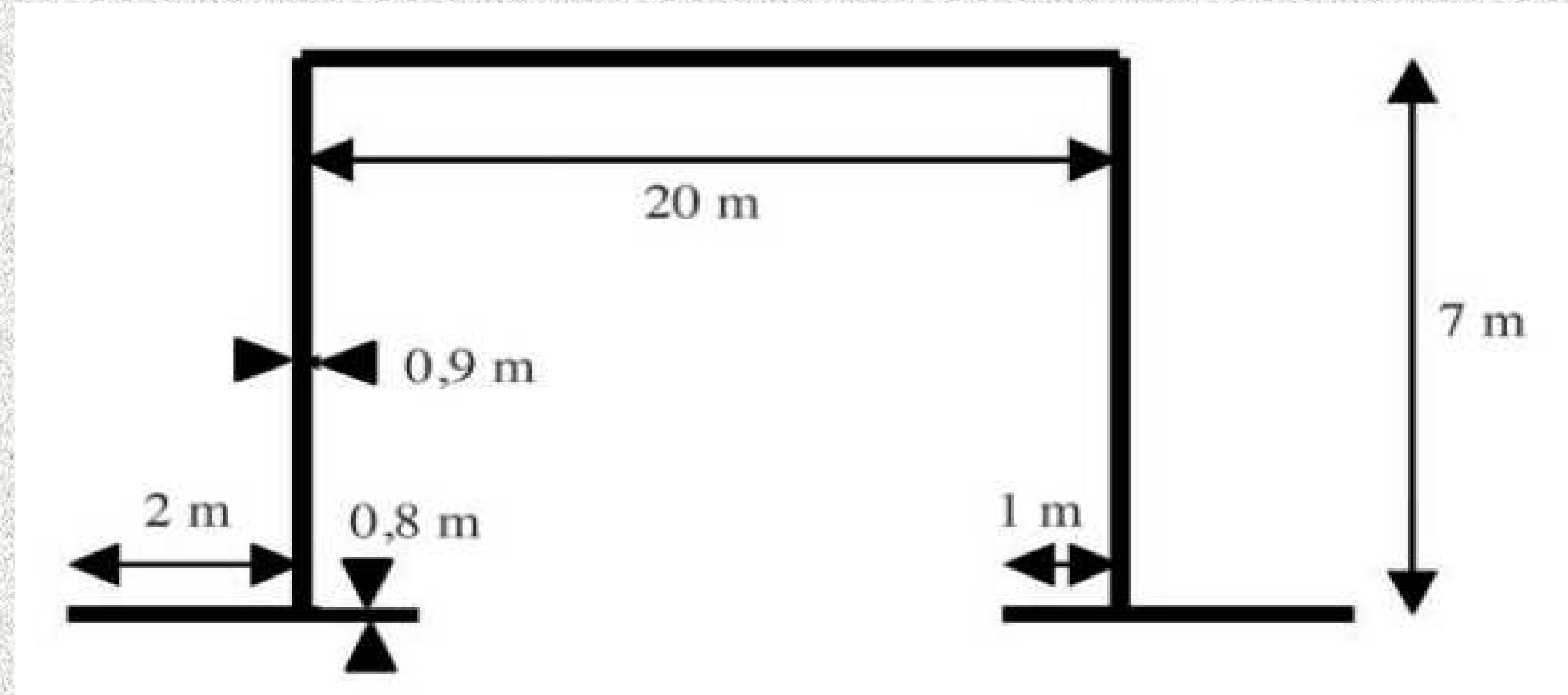


Input parameters are:

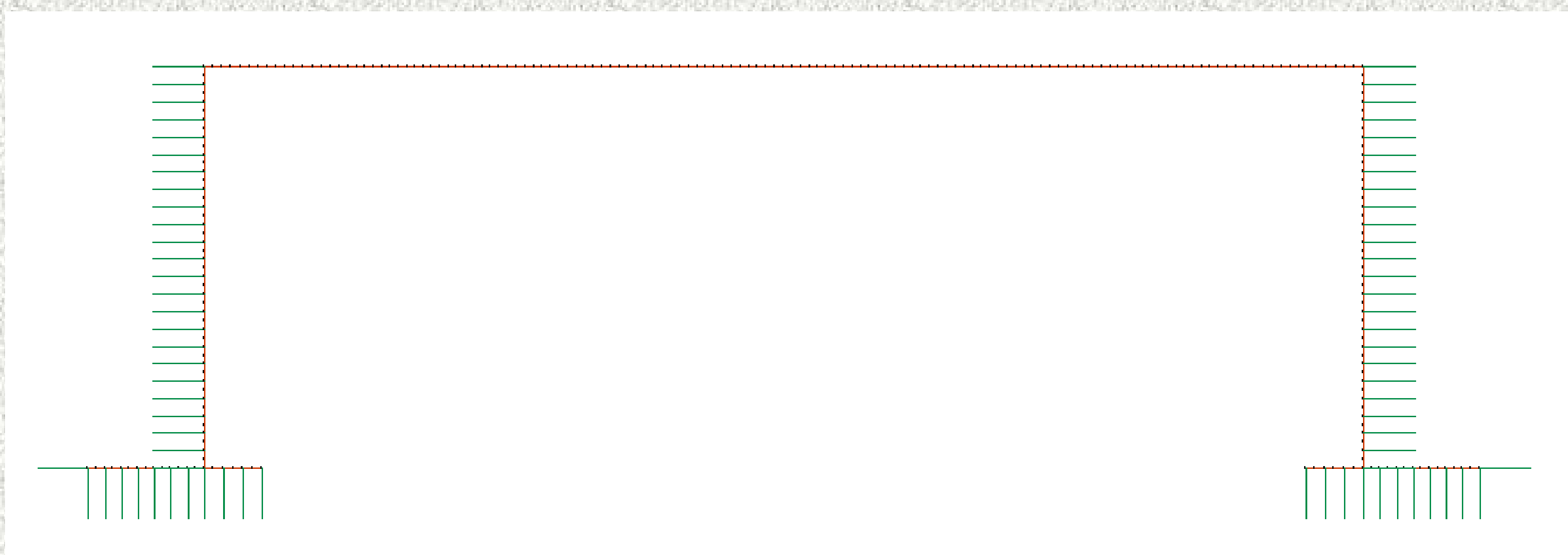
NSPR:	Number of the element.
NNODE:	Node where this element is attached.
CX:	Cosinus of the angle between X axis and this element.
CY:	Cosinus of the angle between Y axis and this element.
CZ:	Cosinus of the angle between Z axis and this element.
F_s	Superior limit of the load.
F_{inf}	Inferior limit of the load.
K	Stiffness of the element for elastic loading or unloading.
A	Area of influence (all forces are multiplied by A).
D_i	Displacement in the configuration of reference (time $t = 0$).
F_i	Force in the configuration of reference (time $t = 0$).

Application example

Cut and cover tunnel (Guide d'application from « CETU »)



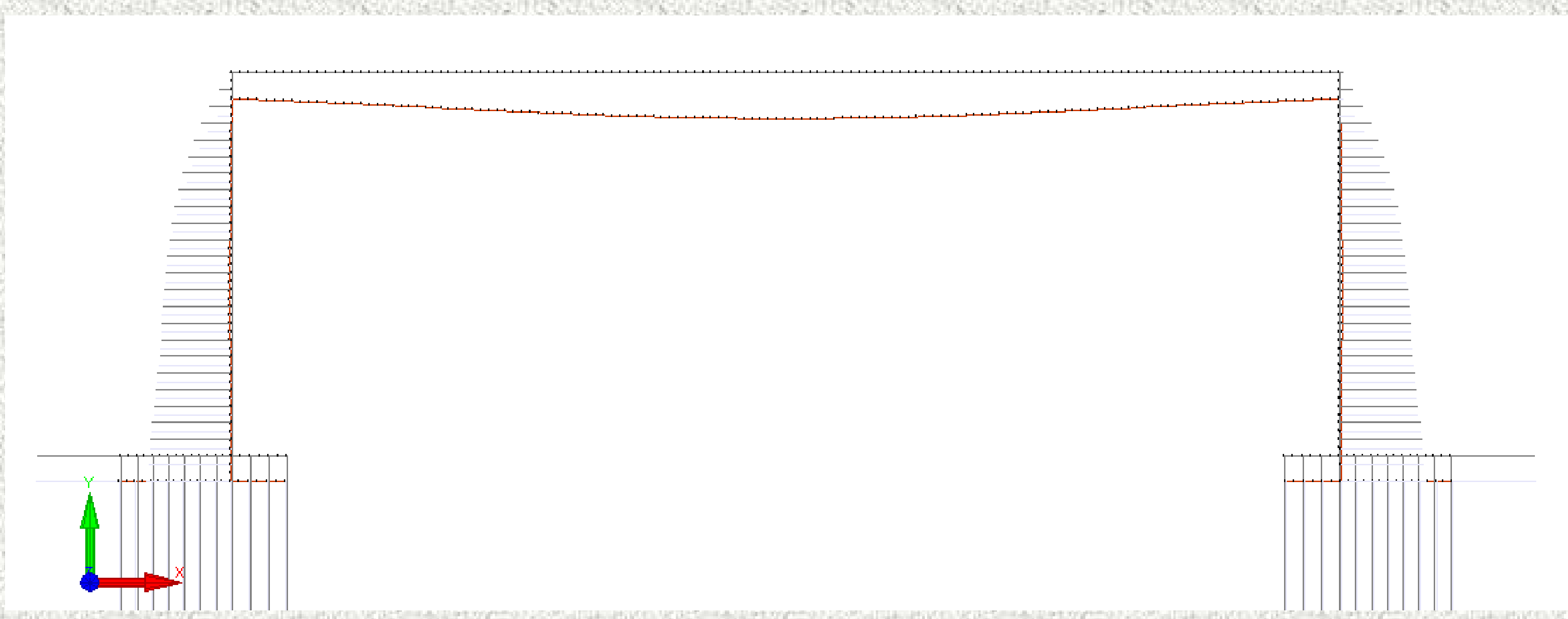
2D model with beam F.E. and spring F.E.



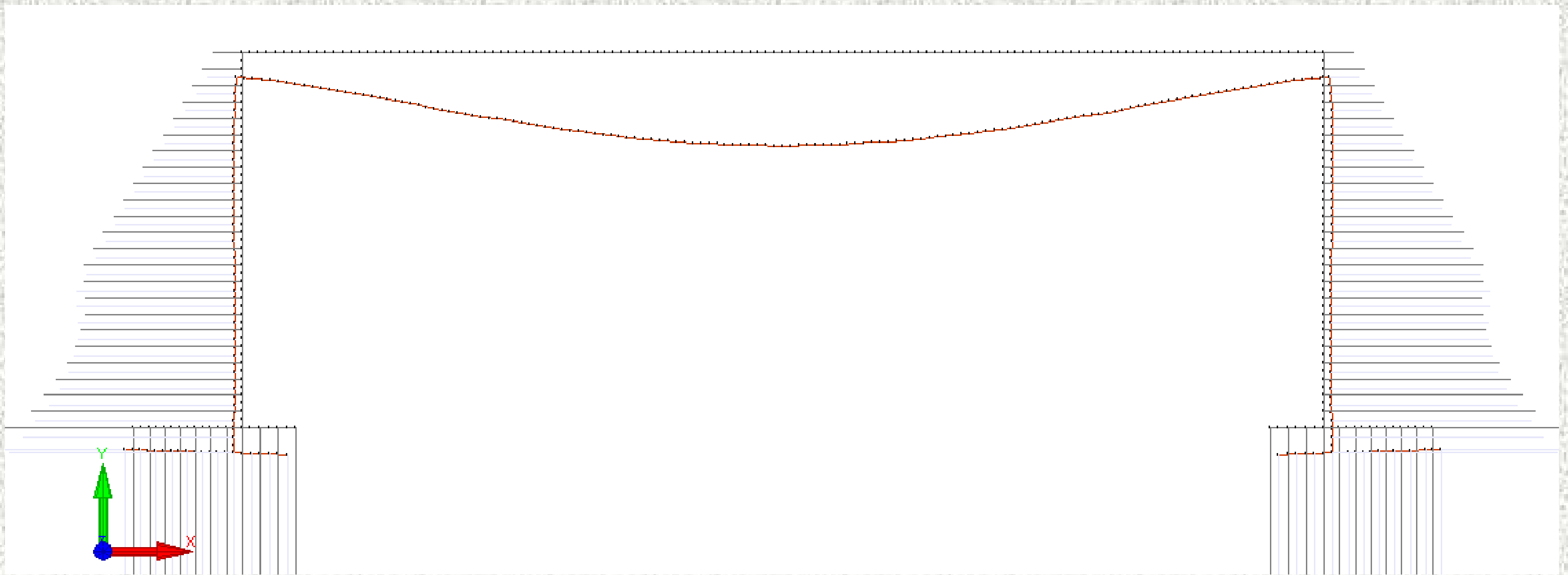
- No restrain
- Trapezoidal loads on the walls replaced by spring F.E.

Deformed shape and soil pressures at t = 60 s

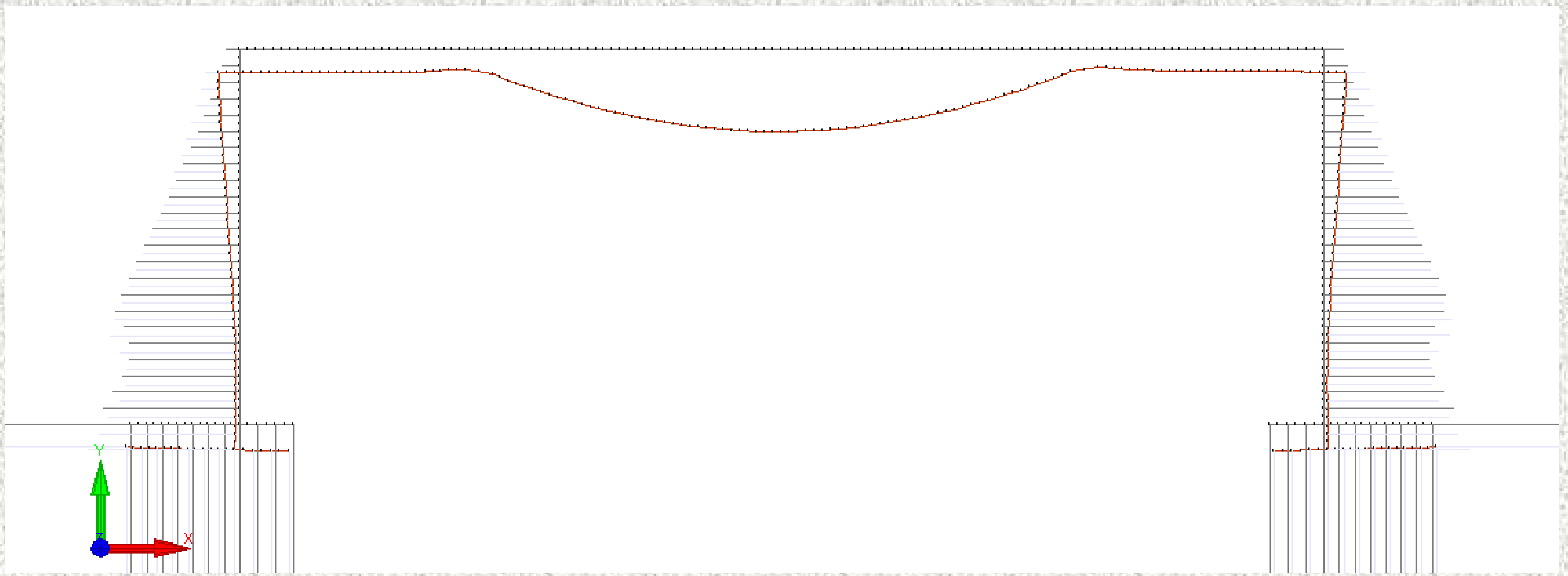
Note: Diamond can plot the loads F or the pressure F/A in the spring elements



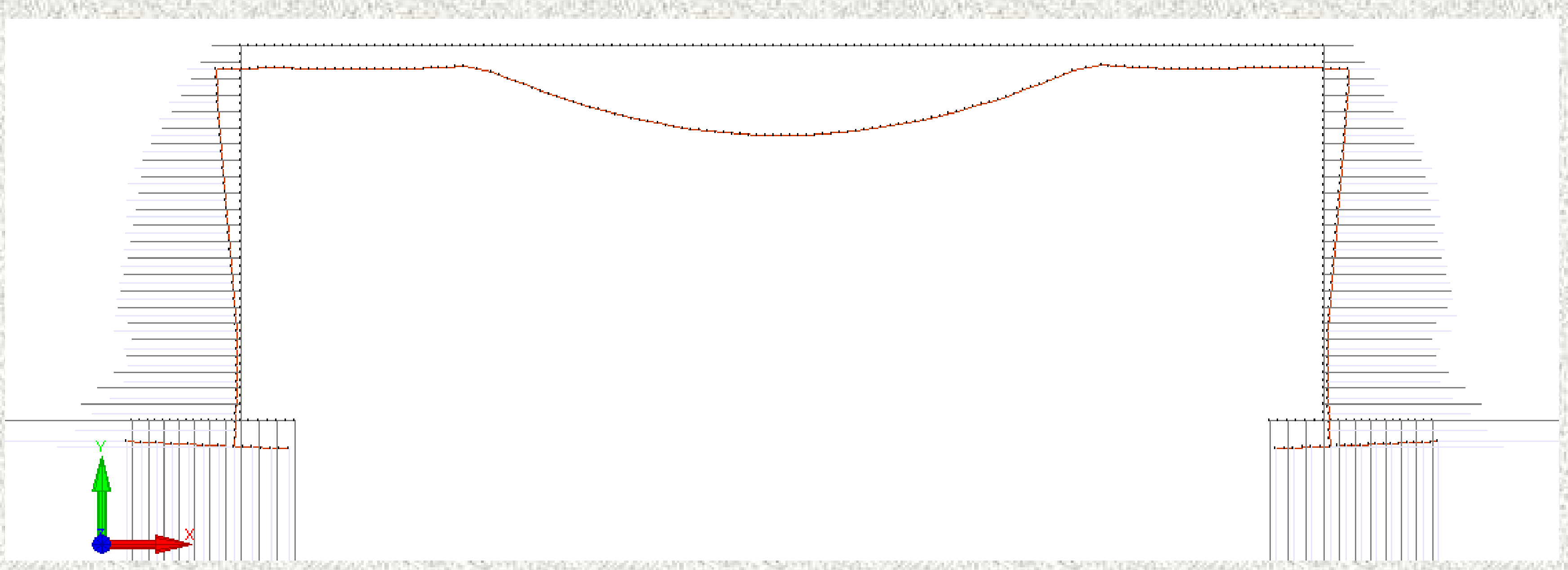
Deformed shape and soil pressures at t = 3 720 s
(just before plastic hinges appear)



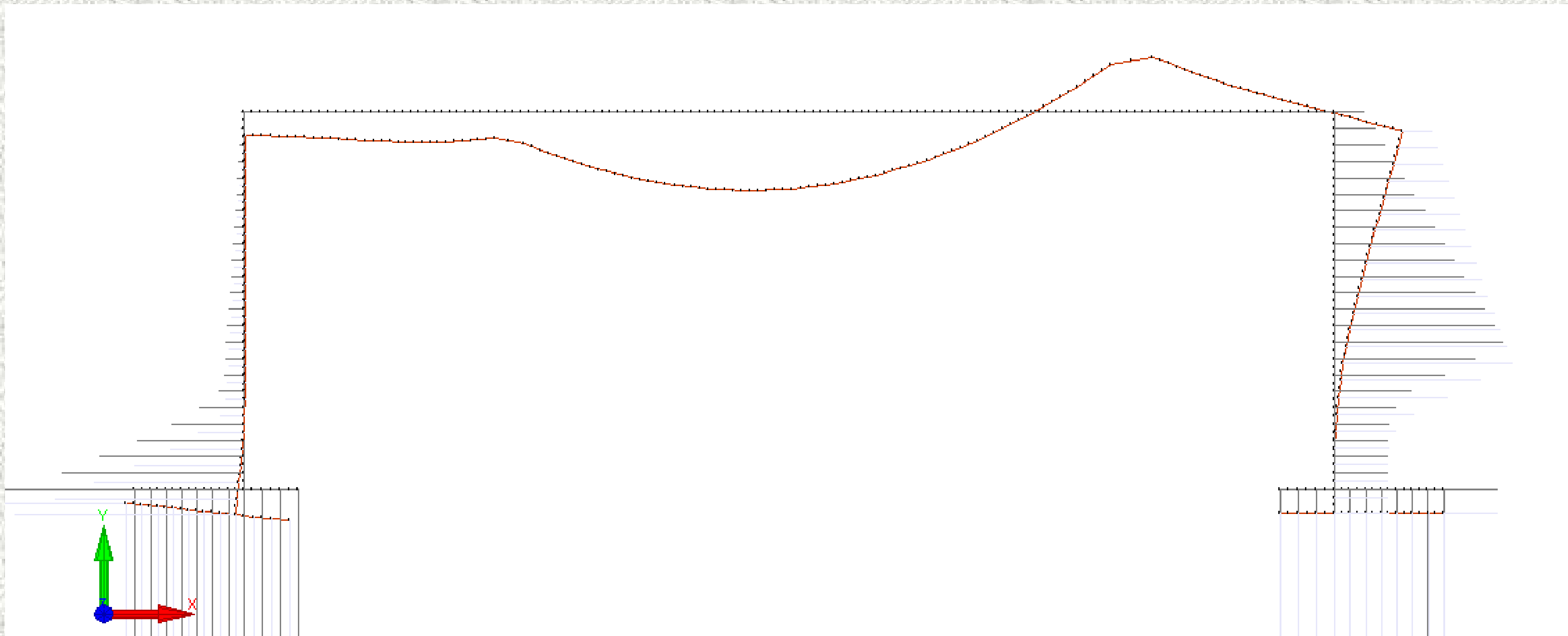
Deformed shape and soil pressures at t = 3 800 s
(just after plastic hinges appear)



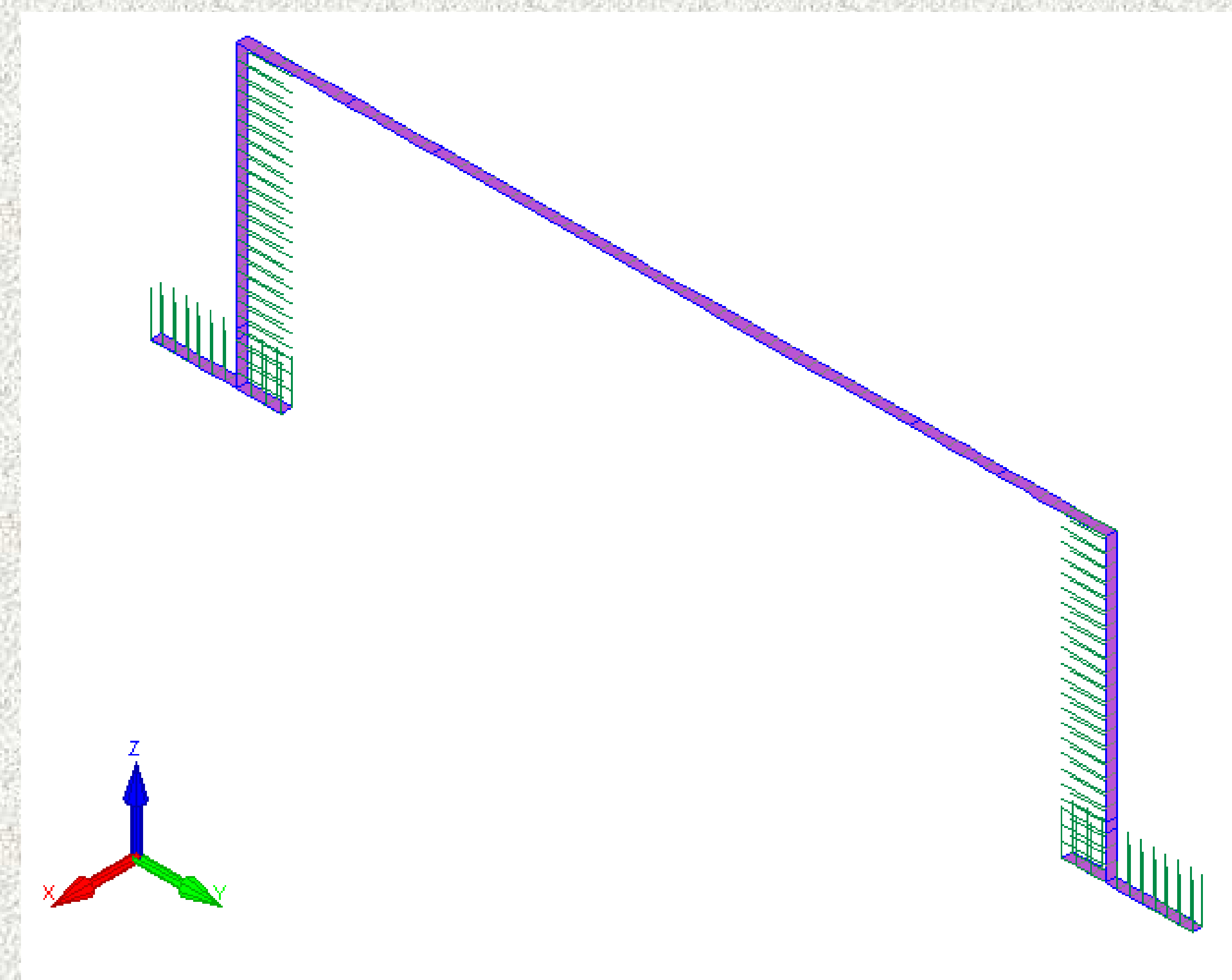
Deformed shape and soil pressures at *t* = 5 135 s (just before failure)



Deformed shape and soil pressures after failure



3D model



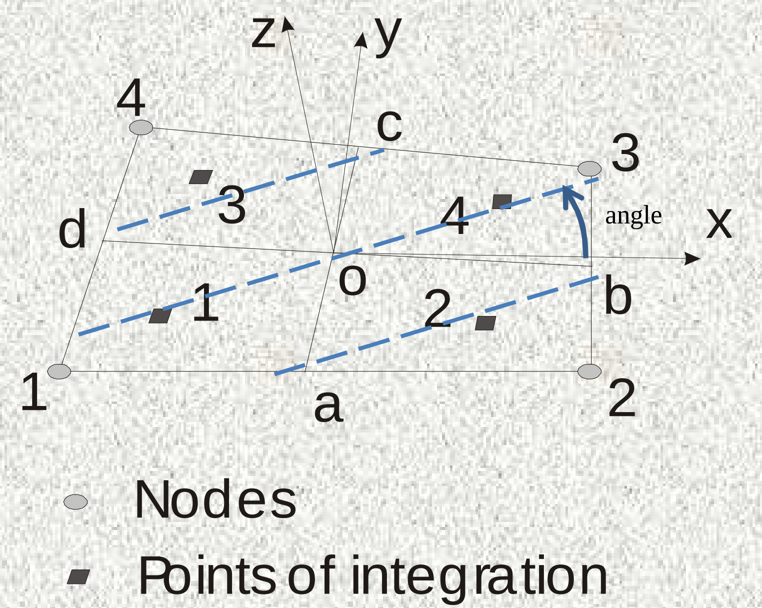
7) Orientation of the re-bars in shell finite elements

For each bar layer, there are two methods to give
the orientation of the bars in the plane of the element.

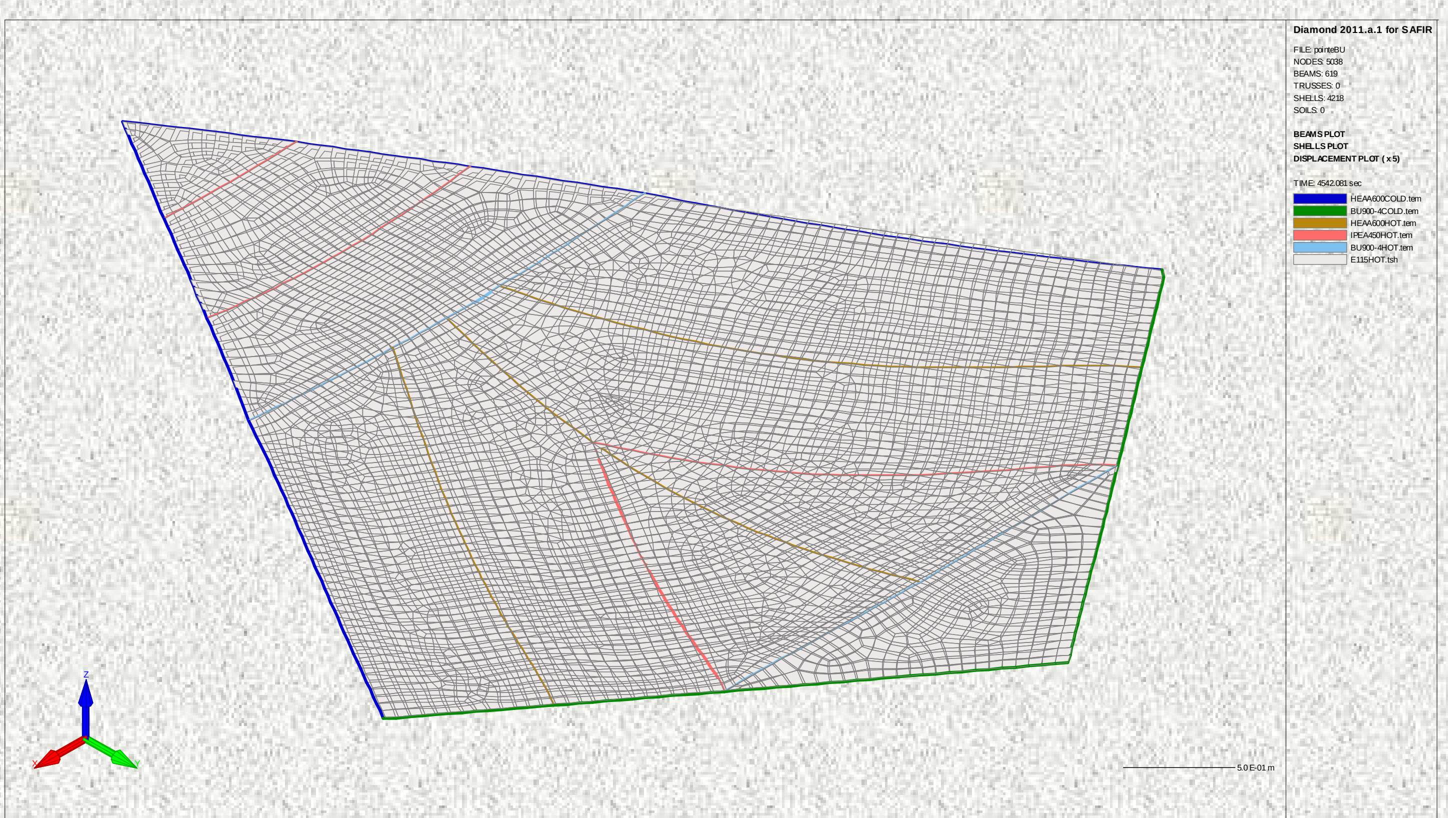
<u>Method 1</u>: with respect to the local system of coordinates of each element.

1 card.
- "ANGLE"
- **angle** Angle in degrees between the local x axis and the layer of rebars, see Figure in which the bars of the layer are represented by doted lines. This angle cannot be smaller than -180°.

.



This method is not appropriate in unstructures meshes



Japan Tobacco Intl, Geneva
Model: Ingeni (courtesy Lorenzo Lelli)

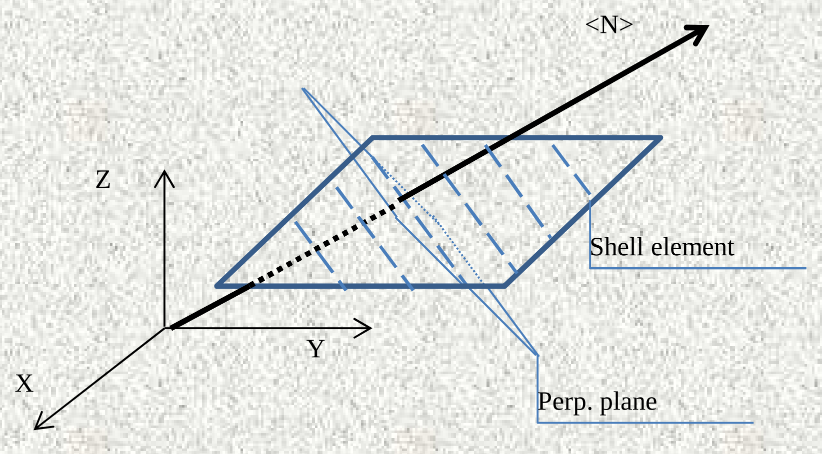
<u>Method 2</u>: with respect to the global system of coordinates of the structure.
1 card.
- "NORMAL"
- N_1
- N_2
- N_3

< N_1 ; N_2 ; N_3 > is a vector in the global system of coordinates of the structure. The norm of the vector does not have to be 1.

This vector is used to define the position of the bar layers in the shell elements with respect to the global system of coordinates according to the following technique, see Figure.

The bars have the orientation of the line which is the intersection between the shell element and a plane that is perpendicular to the normal.

If the norm of the vector is 0, then the orientation of this bar layer is perpendicular, in each element, to the previous bar layer (not possible for bar layer 1).



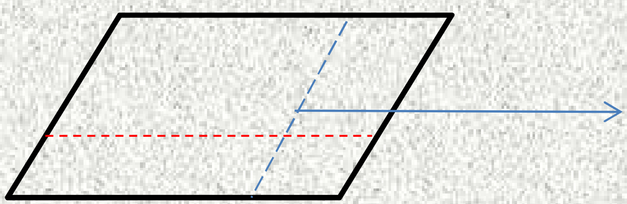


Figure 3: bars in a plate.
Use method 2 if the mesh is unstructured

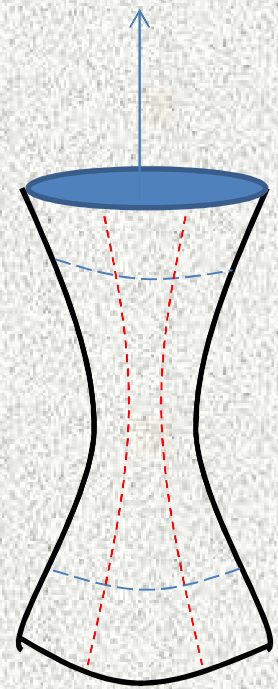


Figure 4: bars in a hyperbolic paraboloid

Method 2

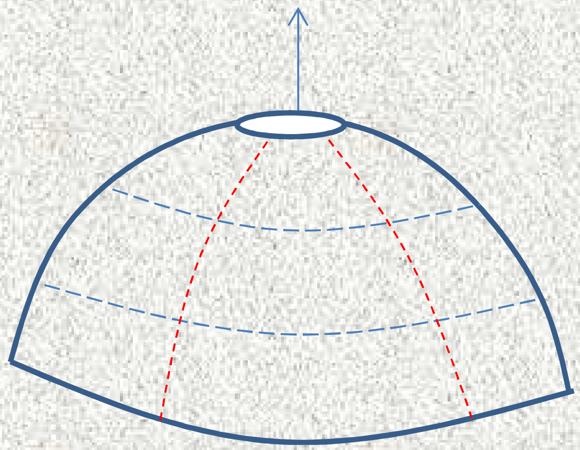


Figure 5: bars in a dome

Method 2

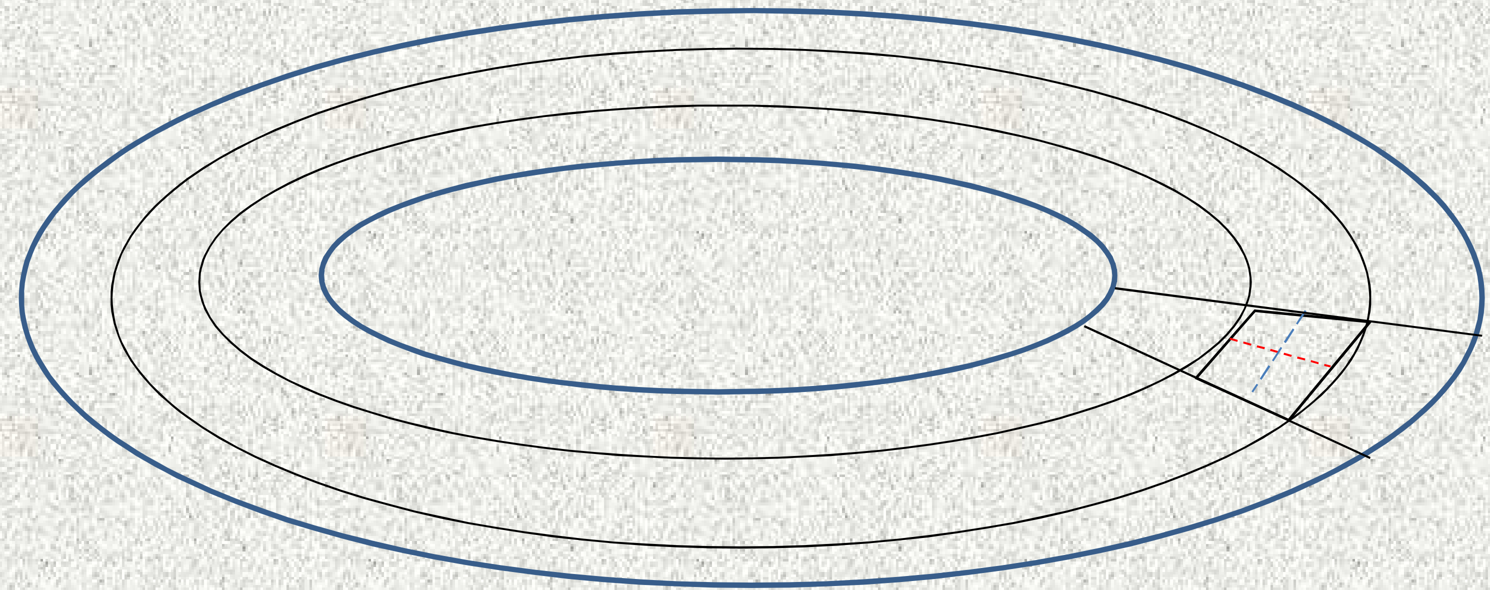


Figure 6: bars in a circular ring

Method 1

ACKNOWLEDGEMENT
DEVELOPMENT OF THE SECOND METHOD HAS BEEN SUPPORTED BY « HOLMES FIRE »

8) LOCAFI fires

See presentation by François Hanus.

8) New DIAMOND

Completely translated in C++

Many subroutines modified

New features (limited)

More easily adaptable (format of output numbers)

Can read and treat bigger files

Opens faster

Output file in XML format (you can use or develop your own viewer)


```
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<P2> 0.15000E+00</P2>
</N>
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<N>    13</N>
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</S>
```

Additional new features?

1) Make your wish list.

2) Be patient because

3) debugging must come first!

Distribution policy

- ✓ Free for licences bought in 2015
- ✓ Demo versions: free
- ✓ Academic licences: 200 Euros (-20% for SWS members)
- ✓ Commercial licences: 1 000 Euros (-20% for SWS members)


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Thank you