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

Jean-Marc Franssen

jm.franssen@ulg.ac.be

University of Liege

SAFIR

Basic theory of the Shell F.E.

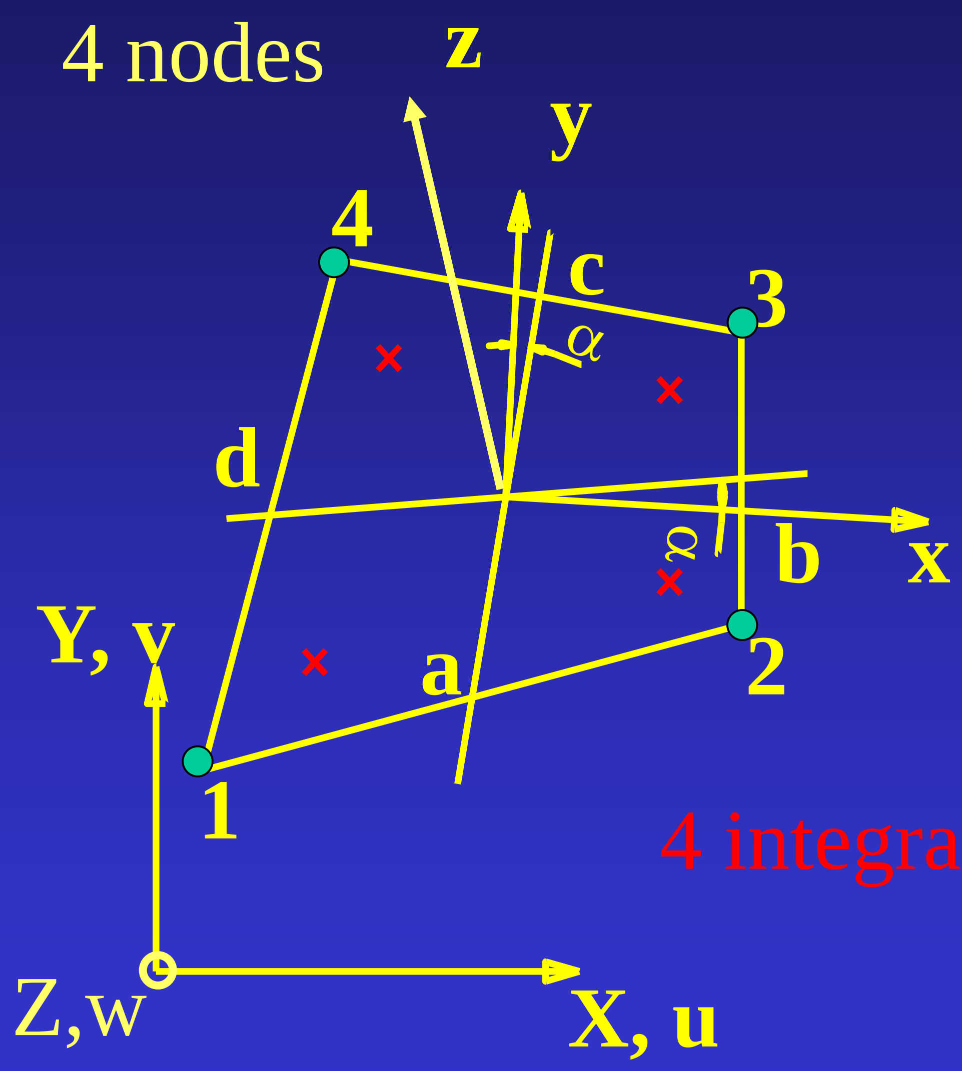
Three steps in the structural fire design:

1. *Define the fire (not made by SAFIR).*
2. *Calculate the temperatures in the structure.*
3. *Calculate the mechanical behaviour.*

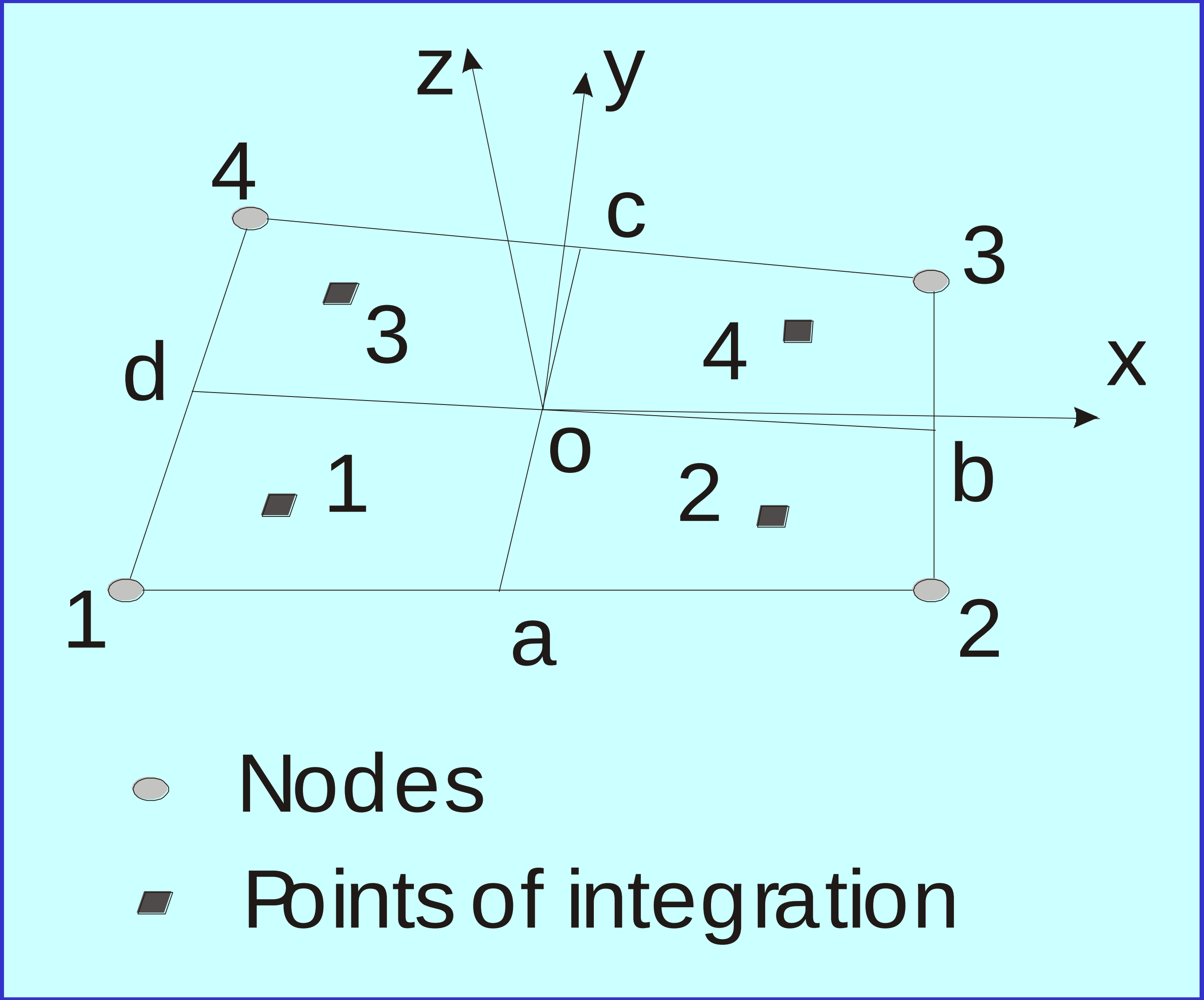
The Shell Finite Element

4 nodes

Uniform thickness

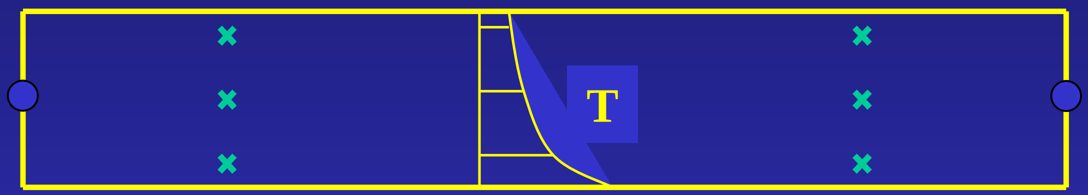


4 integration points on the surface


z
y
4
c
3
3
4
d
x
o
1
2
b
1
a
2
Nodes
Points of integration

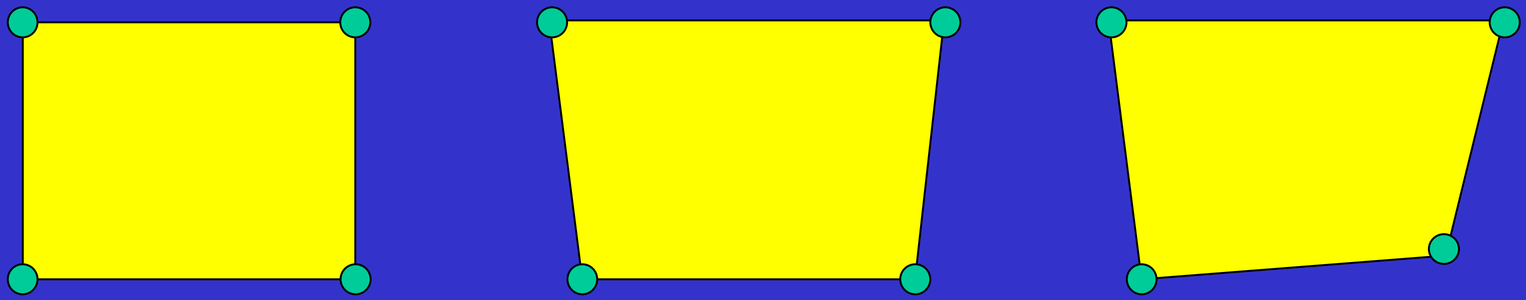
The Shell Finite Element

NG integration points on the thickness



T varies on the thickness of the element.

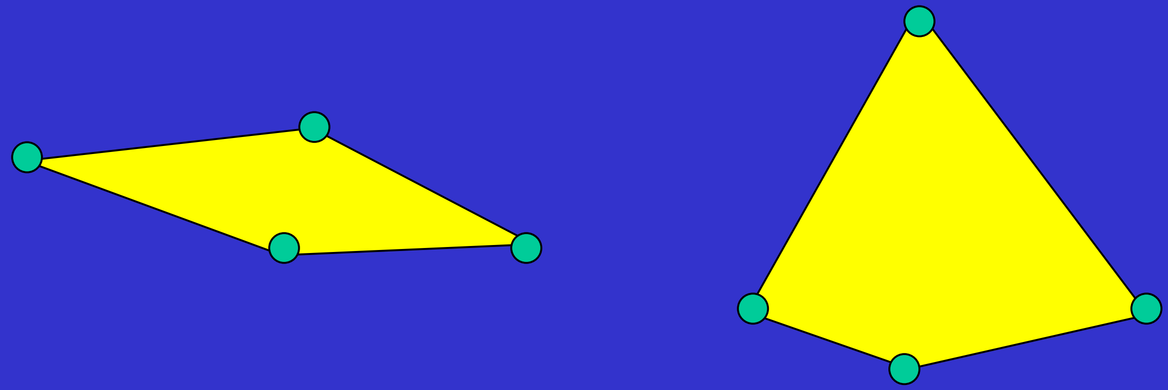
T does not vary in the plane of the element,
except
for HASEMI heating,
for CFD-SAFIR interaction



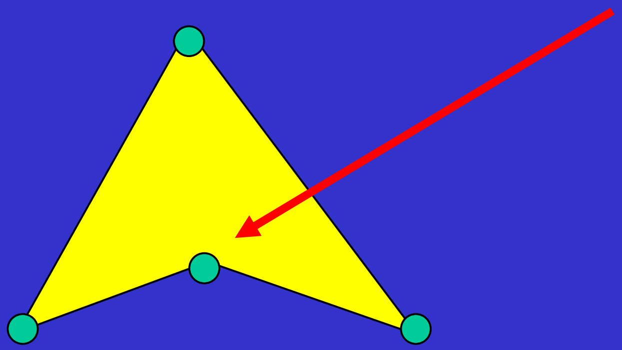
GEOMETRIES OK

NB: The 4 nodes need not be in the same plane

(still, it is preferable not to distort too much out of plane)



GEOMETRIES not recommended



GEOMETRY not accepted

6 D.o.F. at each node of the shell elements:

3 translations and 3 rotations.

$\Rightarrow$One node can be used:

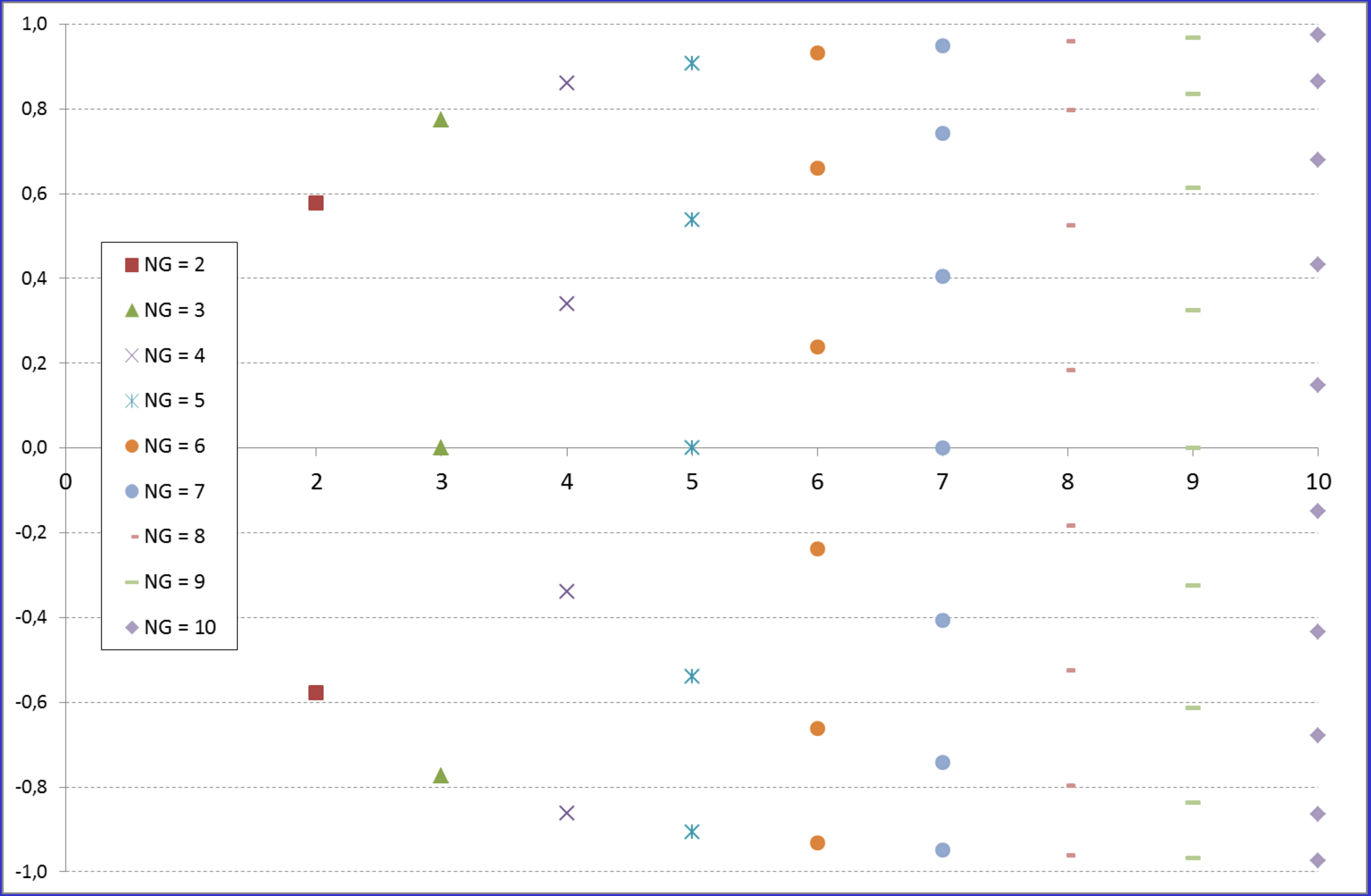
- as the end node of a 3D beam element and
- as the node of a shell element and
- as the node of a truss element.

Membrane behaviour (steel plates): NG = 2

Flexural behaviour (concrete slabs): NG ↑↑ (max. = 10)

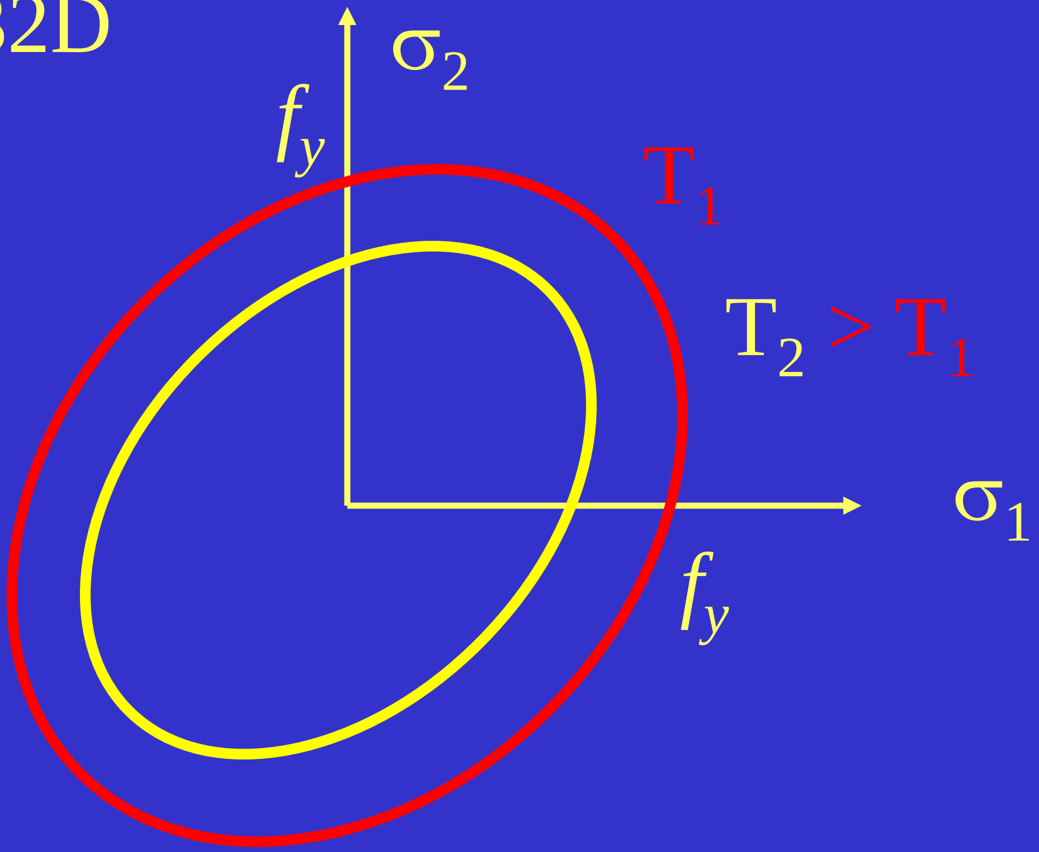
Materials:

- Matrix of the element
  - STEELEC32D (plane stress, very stable)
  - SILCONC2D & CALCONC2D (plane stress, not as stable, a Ph D thesis is under way)
- Eventual rebars
  - STEELEC2 (uniaxial)



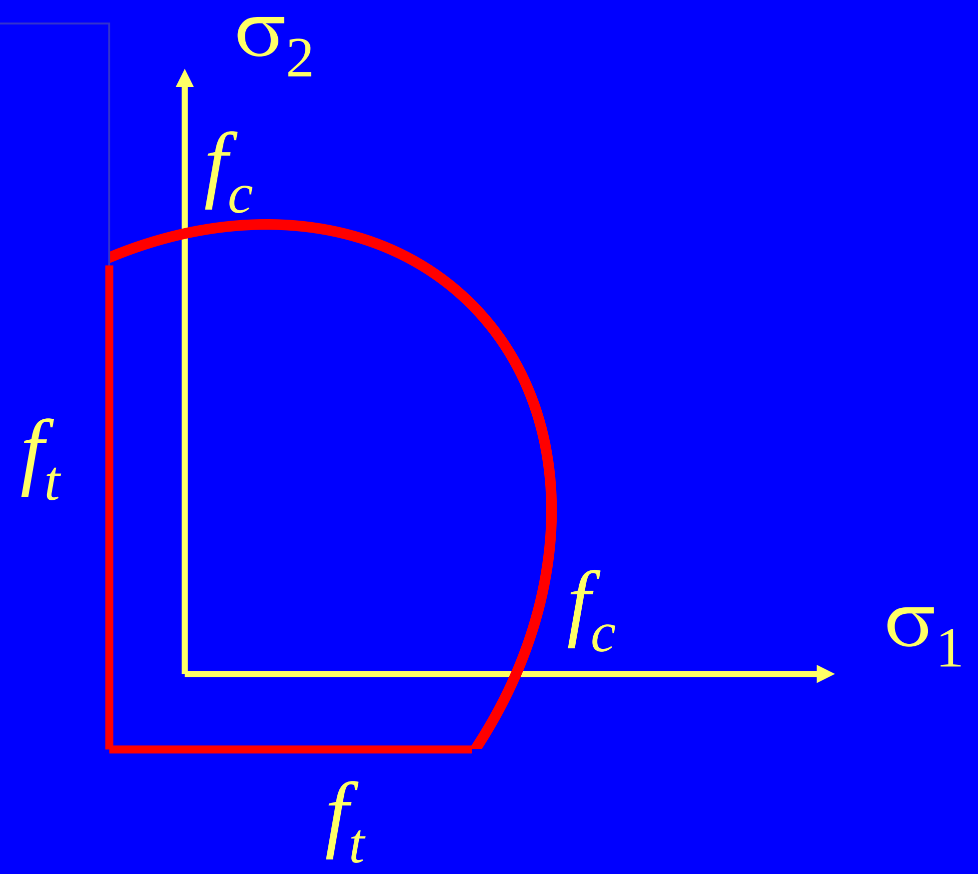
Position of the integration points on the thickness

STEELEC32D



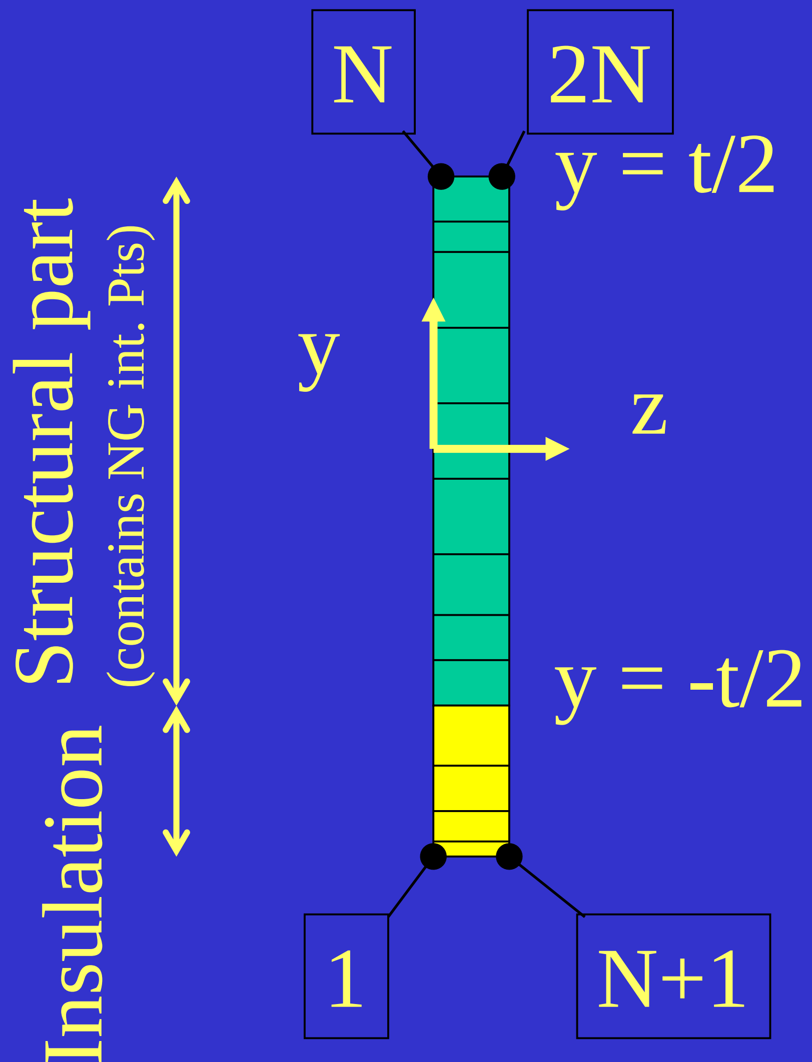
- Associated plasticity
- Von Misses yield surface
- Isotropic hardening (same laws as EN 1993-1-2)

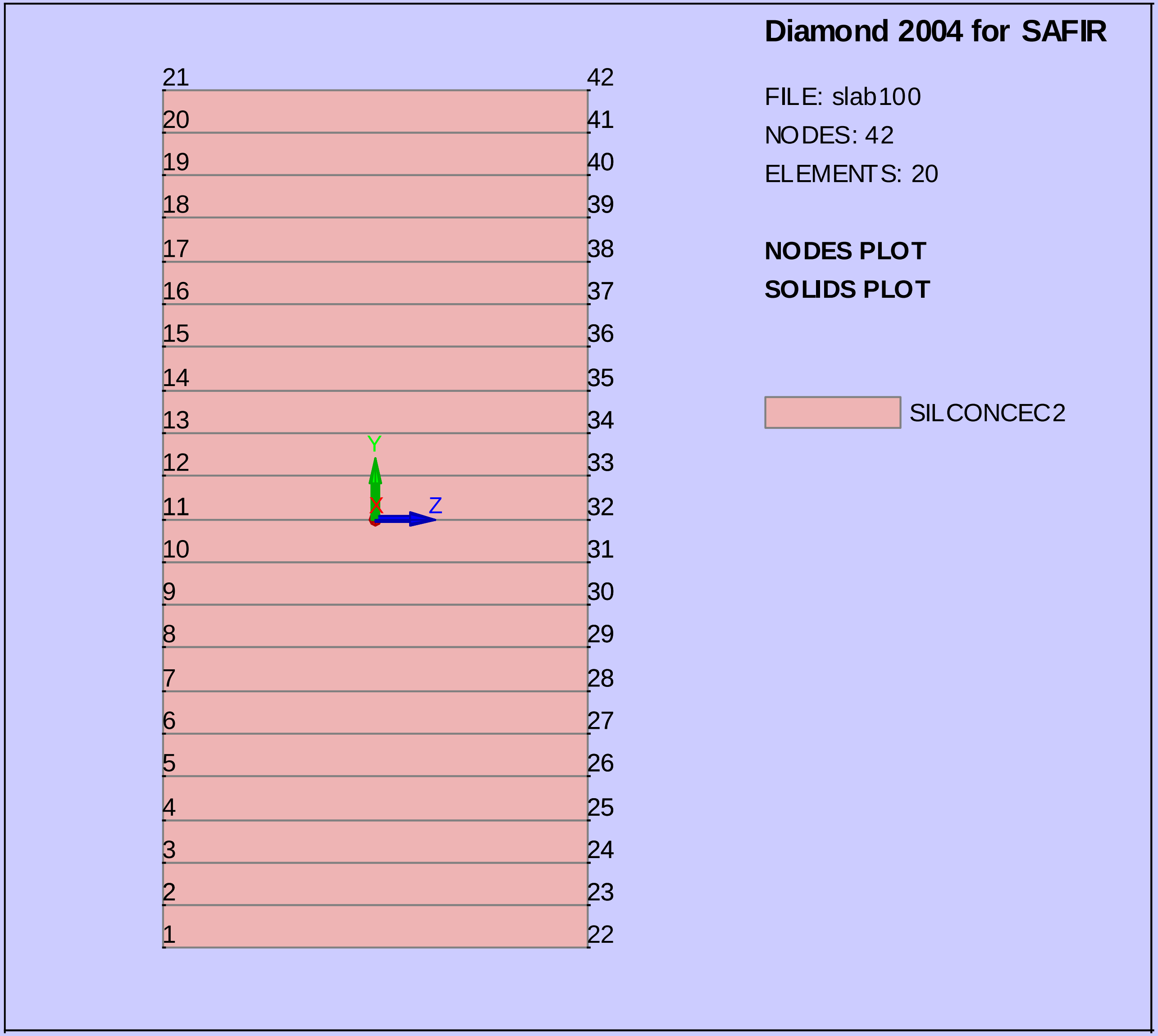
SILCONC2D and CALCONC2D



Temperature distribution: 1D (2D)

MAKE.TSH





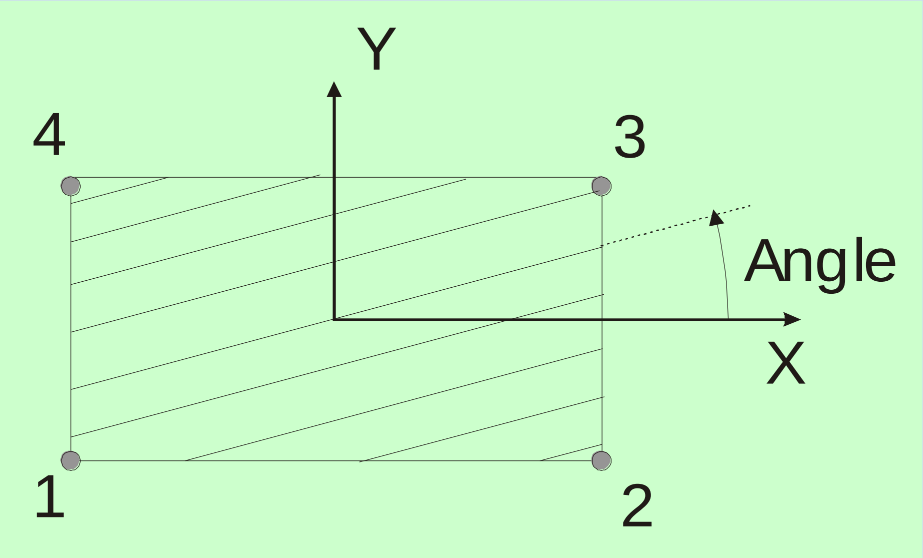
Diamond 2004 for SAFIR
FILE: slab100
NODES: 42
ELEMENTS: 20
NODES PLOT
SOLIDS PLOT
SILCONCEC2
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
Y
X
Z

Different layers of rebars can be present in the element. The rebar layers are horizontal (i.e. parallel to the local **x, y** plane). The rebars are uniformly distributed (layered rebars). Each layer is defined by:

- it's local vertical coordinate **z** in the element (this level must not necessarily coincide neither with the position of a point of integration on the thickness, nor with a position where the temperature has been calculated. Linear interpolations are made);
- it's cross section per unit length of width (m^2/m for example);
- it's material number; and
- the angle between the direction of the rebars and the local **x** axis..

Assumptions for rebar elements are:

- the cross section of the rebar is not subtracted from the plane section of the element. This means that, in a reinforced concrete slab, steel and concrete are supposed to be simultaneously present at the location of the bars,
- the bars resist only axial direction actions. This means that a mesh of perpendicular rebars does not resist shear by itself.



The information about the re-bars of the shells (section, vertical position, orientation, number of the material) have to be entered by the user at the beginning of the file xxx.TSH that gives the temperatures for the relevant section type.

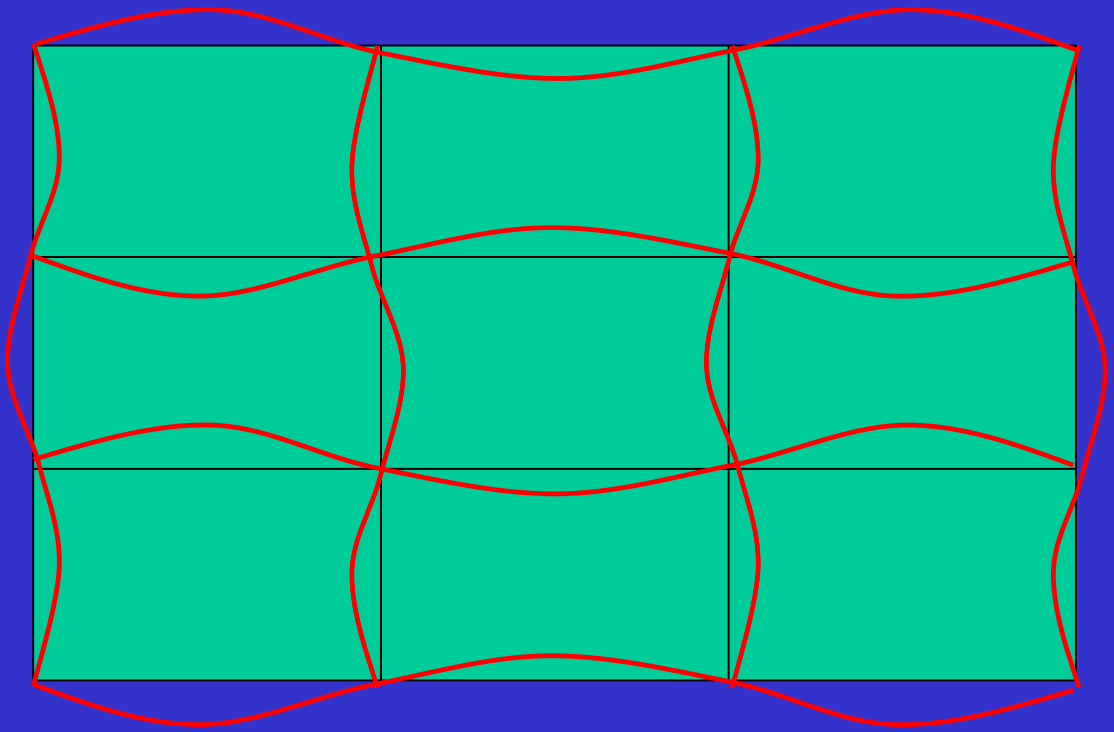
6 cm thick slab

2 layers of re-bars

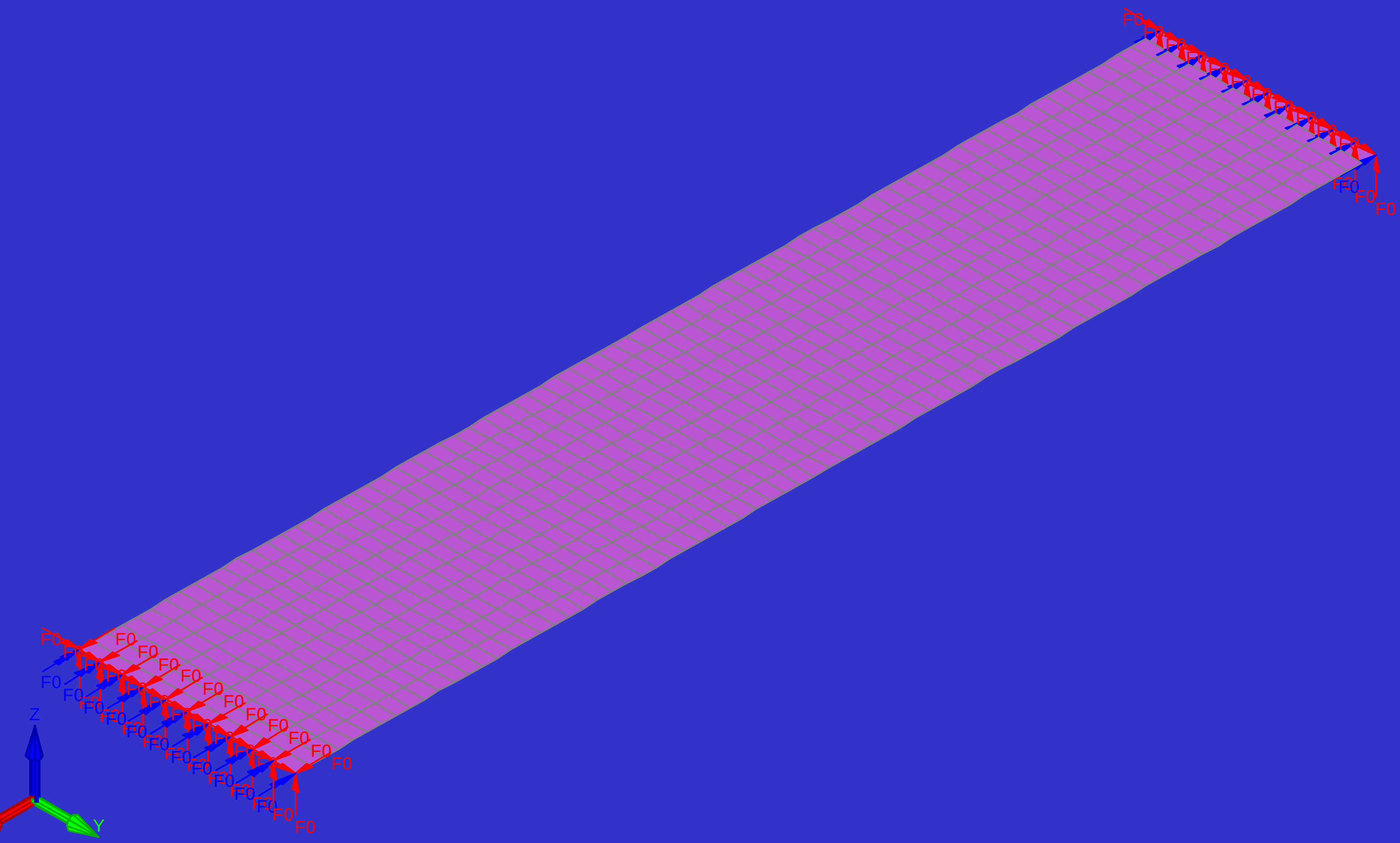
```
 THICKNESS    0.06
  MATERIAL    1
    REBARS    2
  MATERIAL    2
   SECTION    257e-6
     LEVEL   0
     ANGLE    0
  MATERIAL    2
   SECTION    257e-6
     LEVEL   0
     ANGLE    90
```

HOT

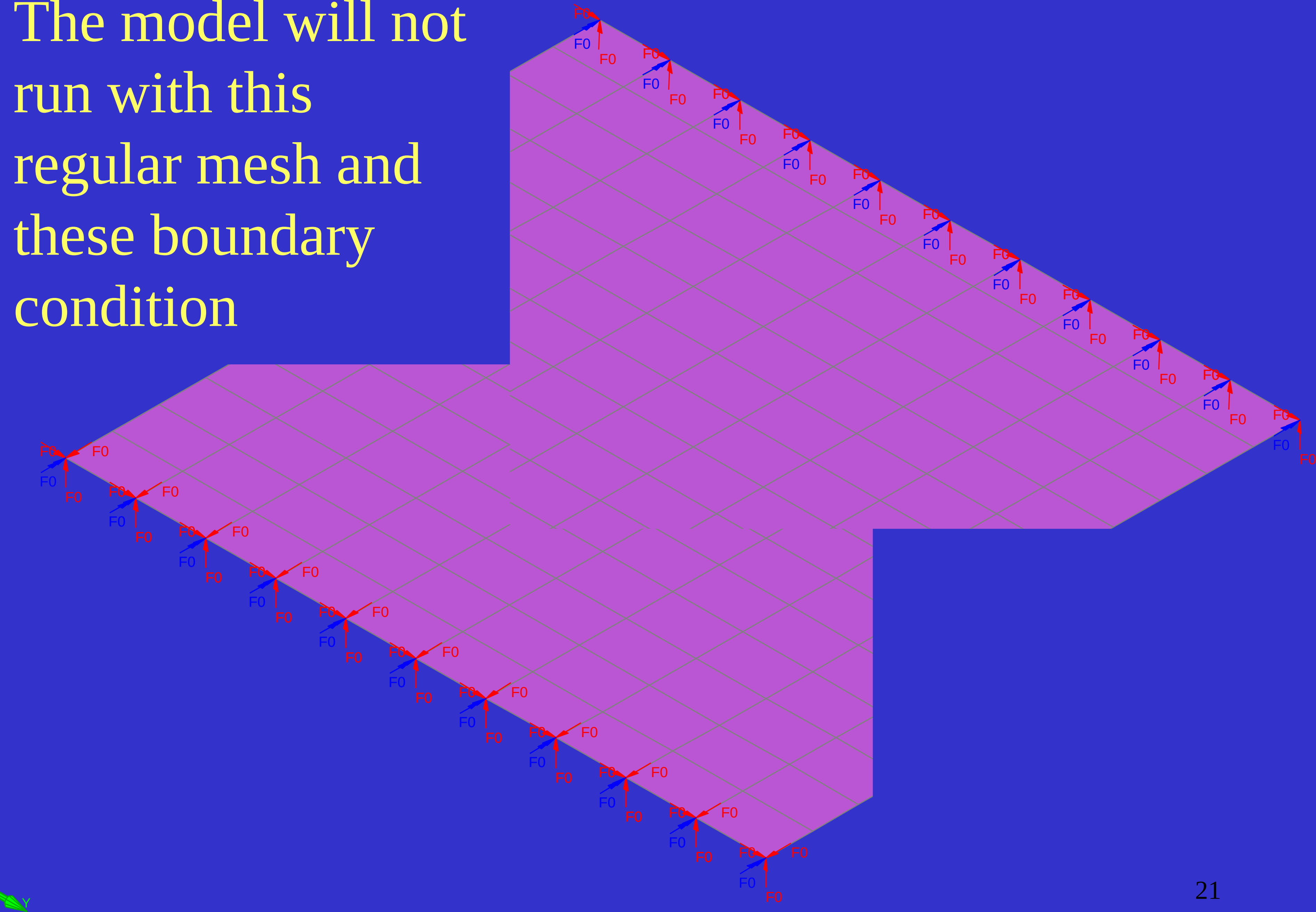
Possibility of spurious modes in perfectly regular meshes



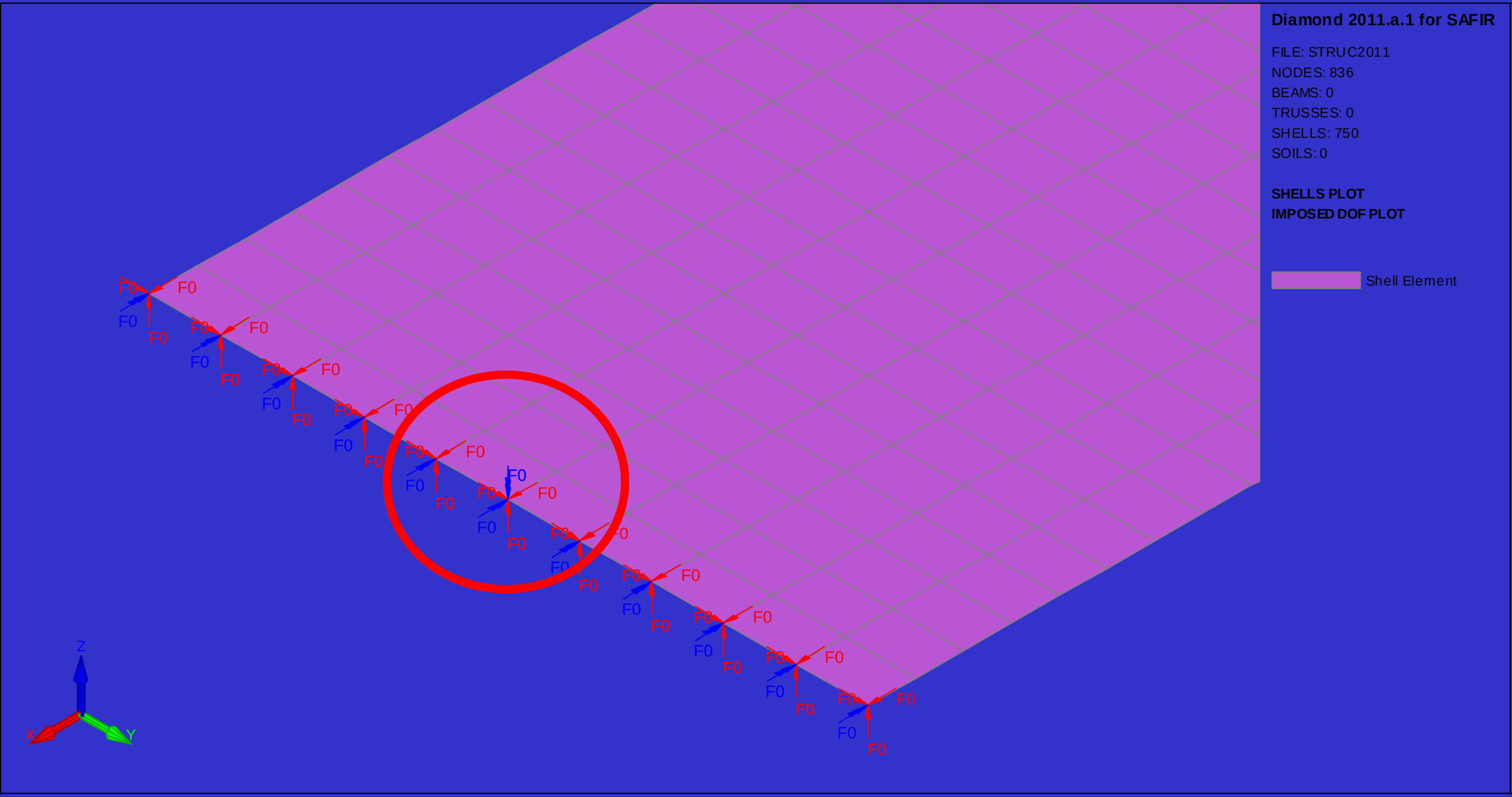
Deformation with no energy activated in the four integr. Pts of each element


F0
Z
Y

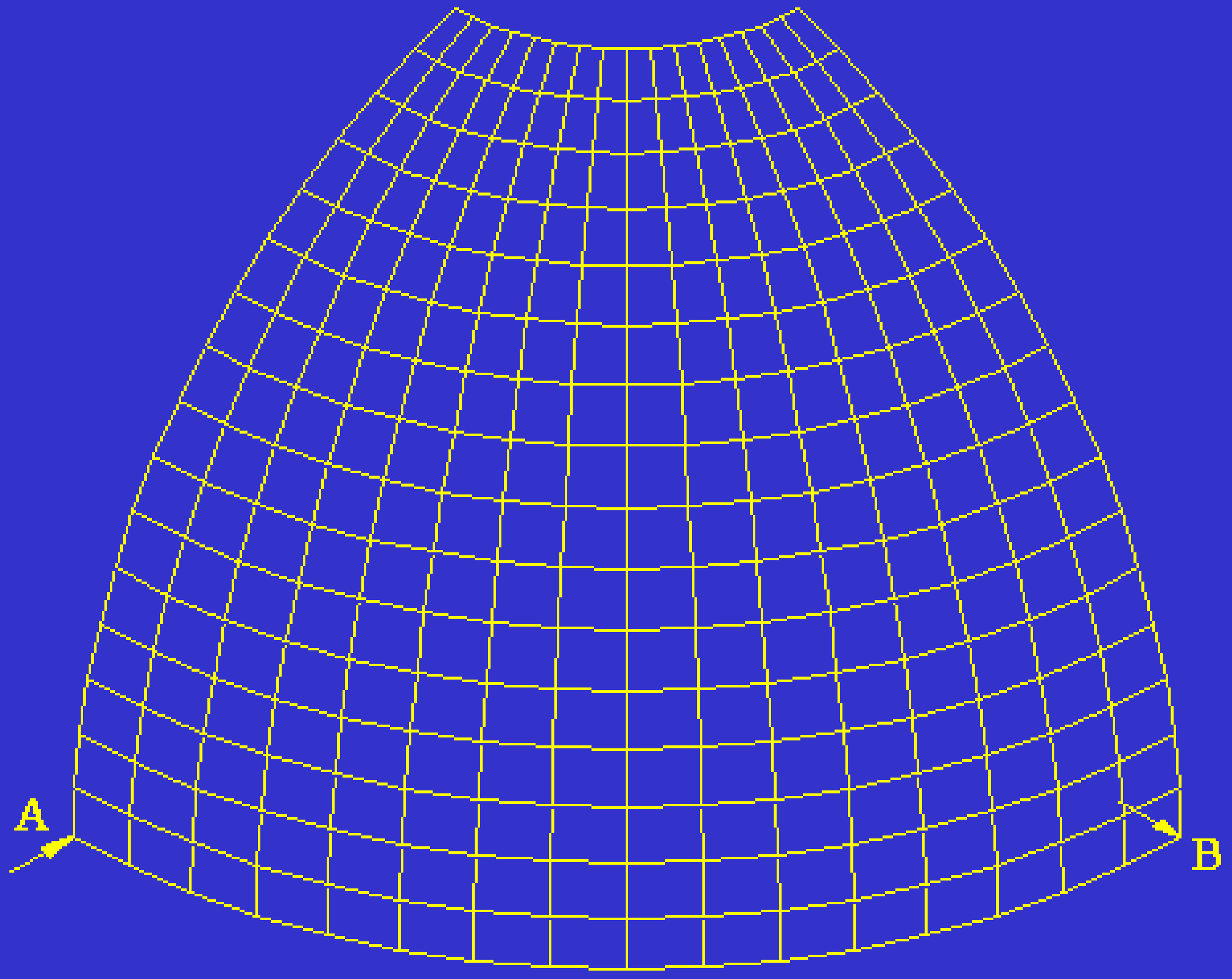
The model will not run with this regular mesh and these boundary condition



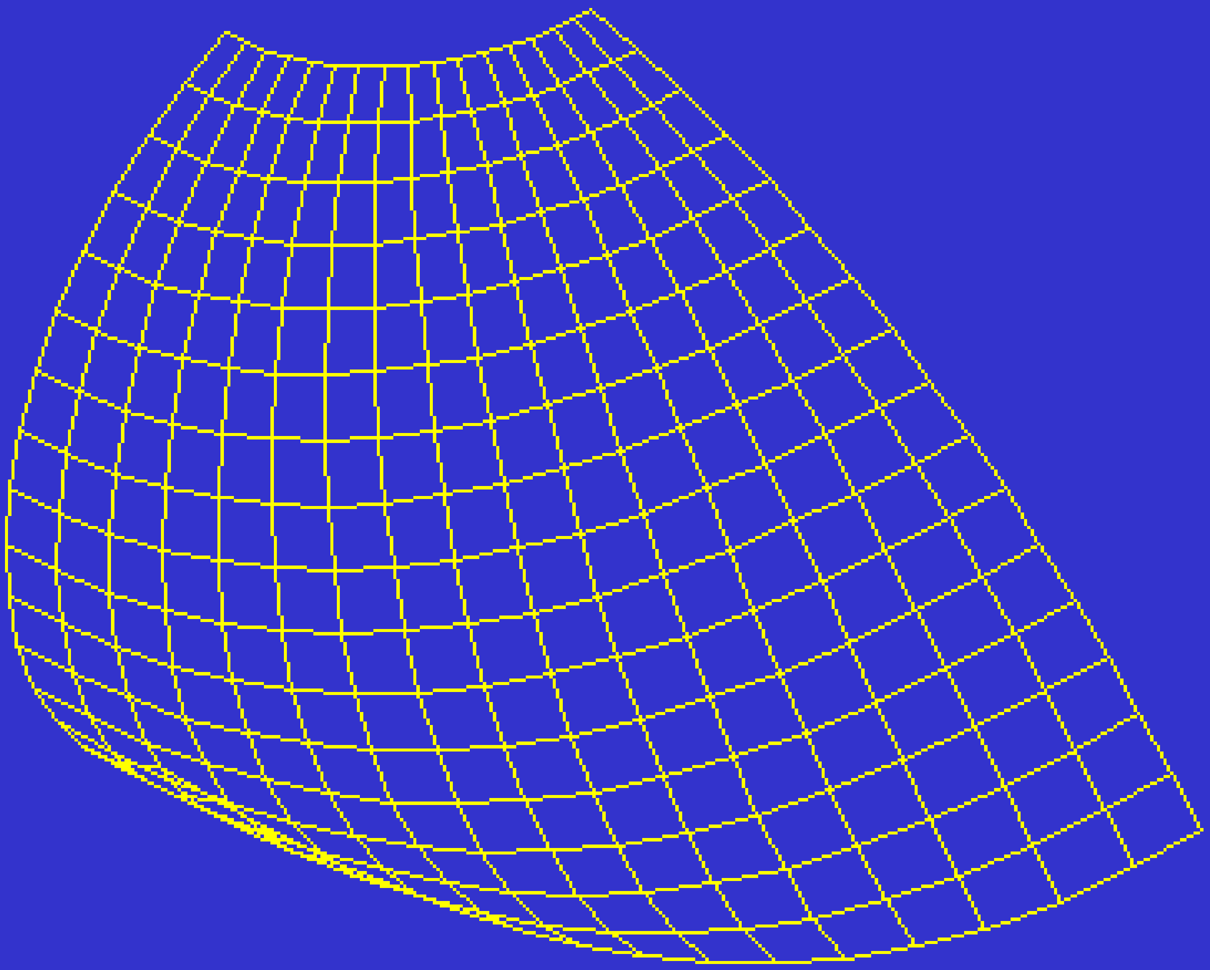
One possible solution



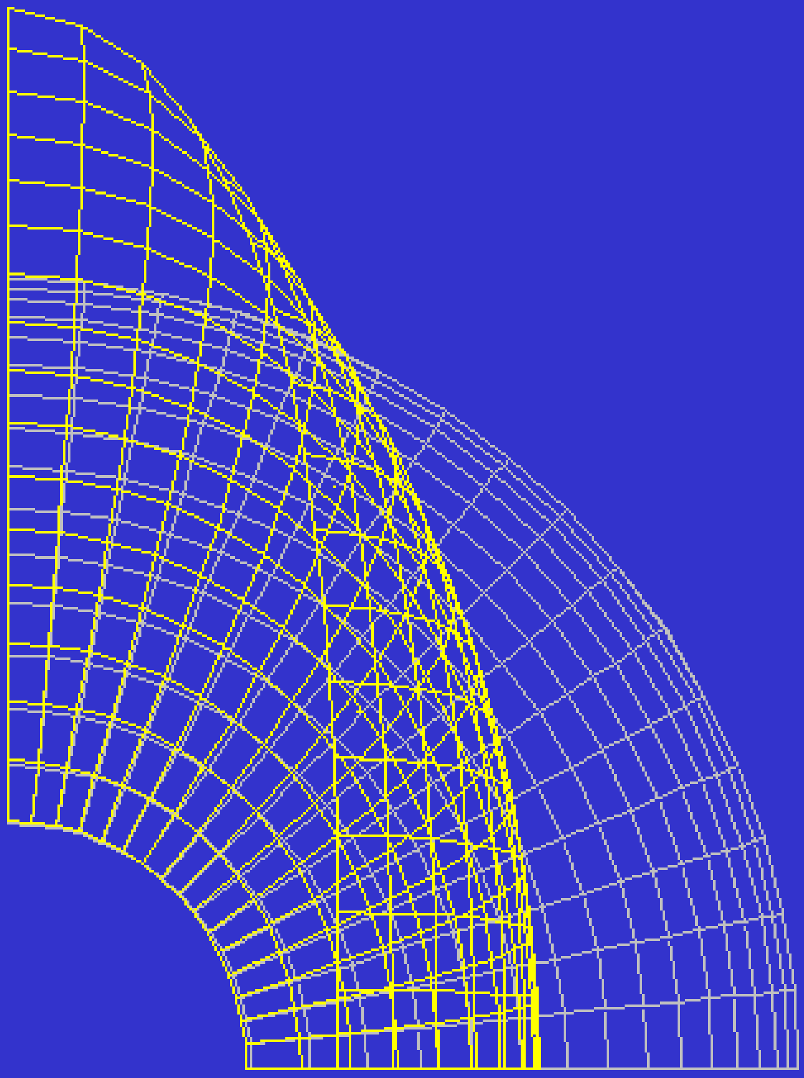
Hemispherical Shell



Deformed Hemispherical Shell

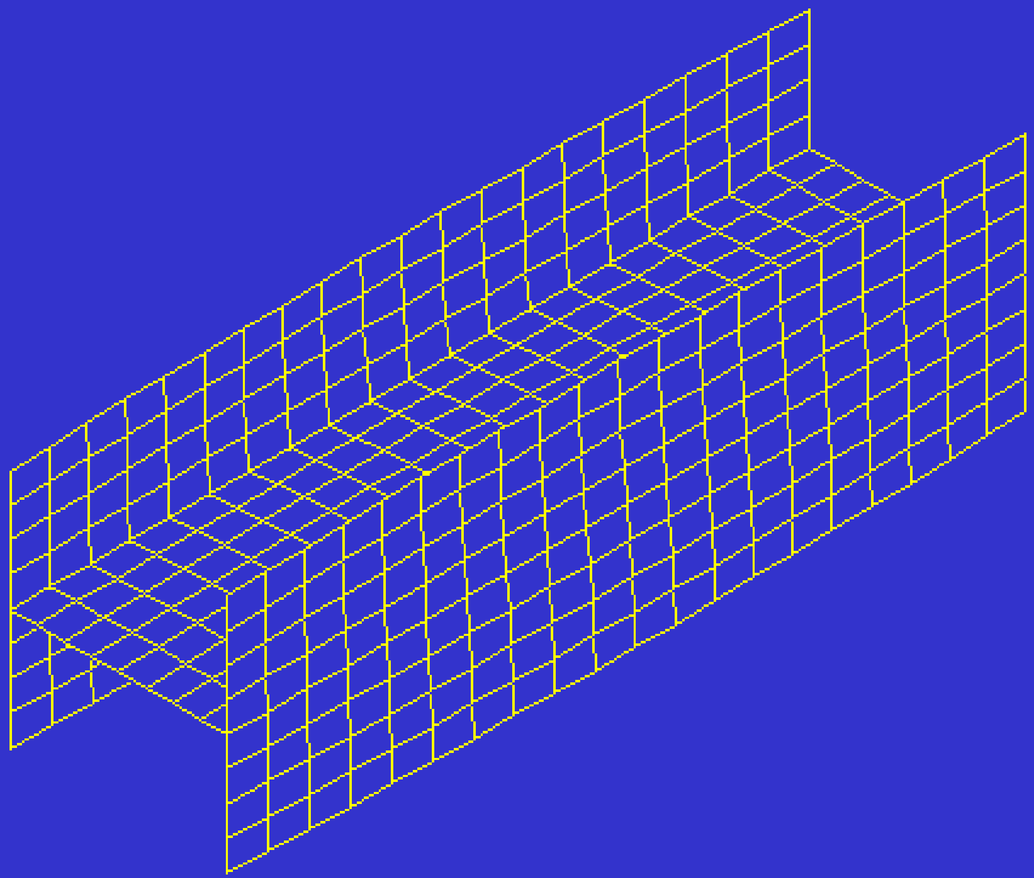


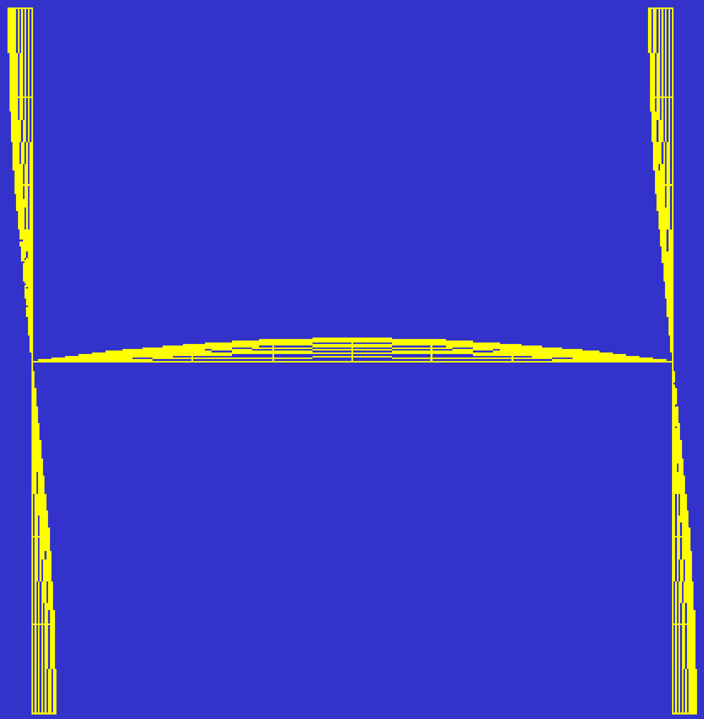
Initial Geometry and Deformed

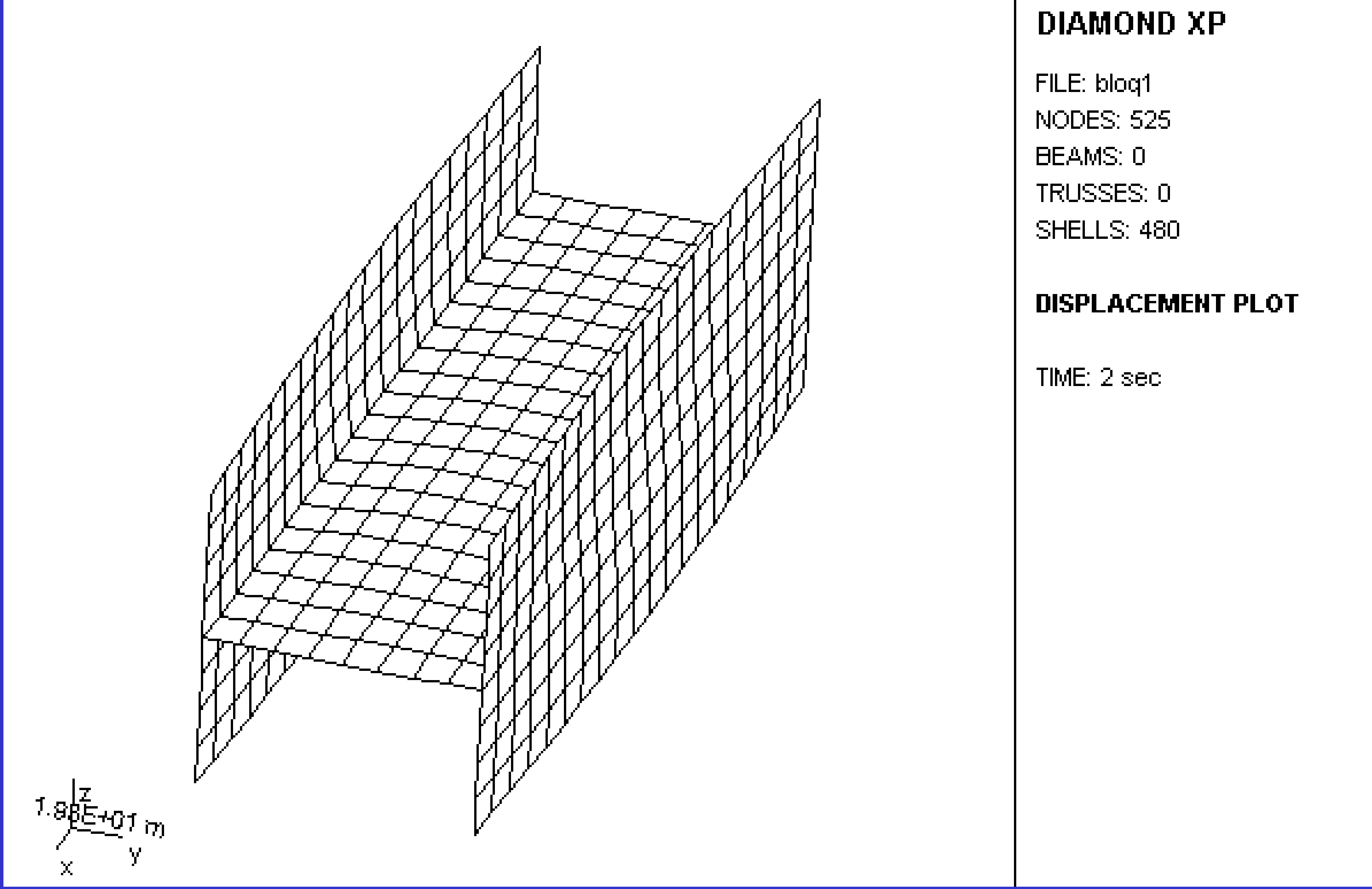


HE 300 AA+

Initial geometry

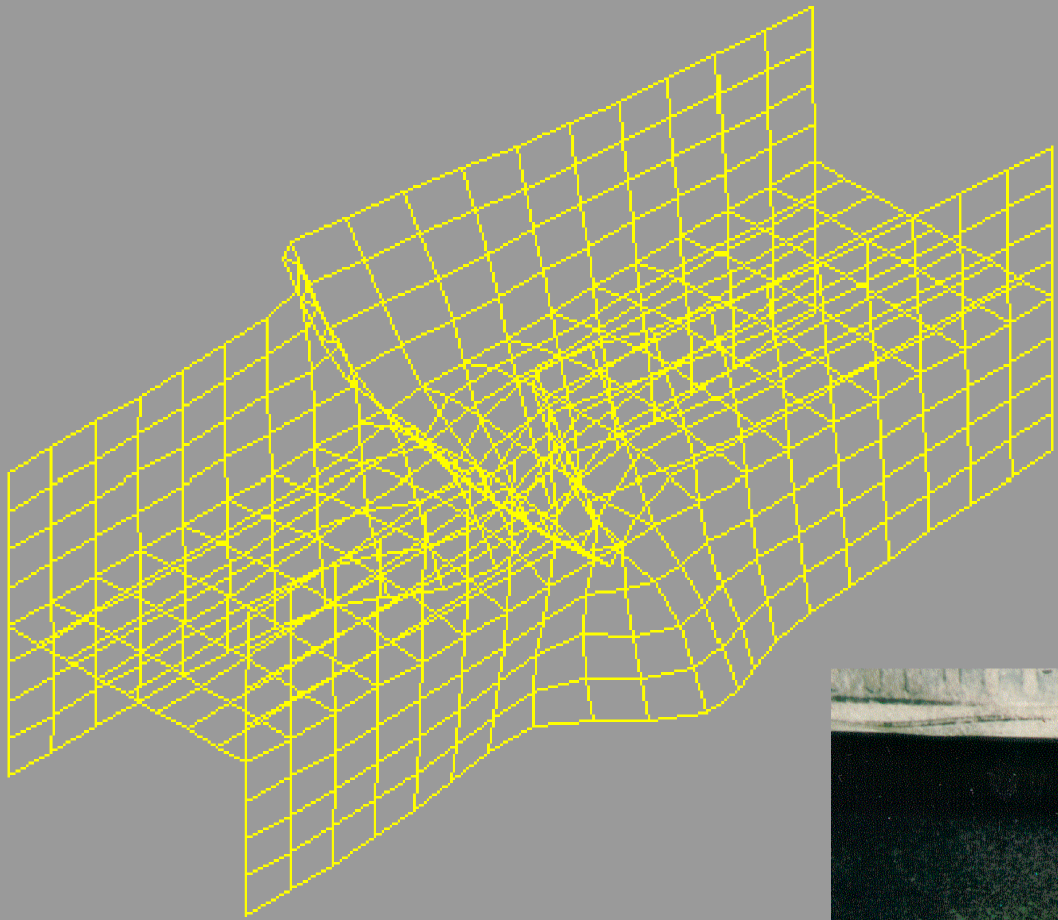






Heating and shortening

(no amplification of the displacements in this animation)




SB6E
PB5

What can be printed about the material behaviour?

```
PRNSIGMASH      1
```

Strains and Stresses

- in the material of the shell [N/mm²]
- in the material of the eventual re-bars

`PRNSIGMASH`

is equivalent to

`PRNSIGMASH` in all shell elements

SHELL:	1, SURF: 1, THICK:	1	ex:	-0.000002	ey:	0.000011	exy:	0.000000
SHELL:	1, SURF: 1, THICK:	1	Sx:	0.30	Sy:	2.40	Sxy:	-0.04
SHELL:	1, SURF: 1, THICK:	2	ex:	-0.000002	ey:	0.000011	exy:	-0.000001
SHELL:	1, SURF: 1, THICK:	2	Sx:	0.28	Sy:	2.29	Sxy:	-0.04
SHELL:	1, SURF: 1, THICK:	3	ex:	-0.000002	ey:	0.000010	exy:	-0.000001
SHELL:	1, SURF: 1, THICK:	3	Sx:	0.26	Sy:	2.11	Sxy:	-0.05
SHELL:	1, SURF: 1, THICK:	4	ex:	-0.000001	ey:	0.000009	exy:	-0.000001
SHELL:	1, SURF: 1, THICK:	4	Sx:	0.22	Sy:	1.88	Sxy:	-0.06
SHELL:	1, SURF: 1, THICK:	5	ex:	-0.000001	ey:	0.000008	exy:	-0.000001
SHELL:	1, SURF: 1, THICK:	5	Sx:	0.18	Sy:	1.64	Sxy:	-0.07
SHELL:	1, SURF: 1, THICK:	6	ex:	-0.000001	ey:	0.000007	exy:	-0.000001
SHELL:	1, SURF: 1, THICK:	6	Sx:	0.14	Sy:	1.41	Sxy:	-0.08

What can be printed about the material behaviour?

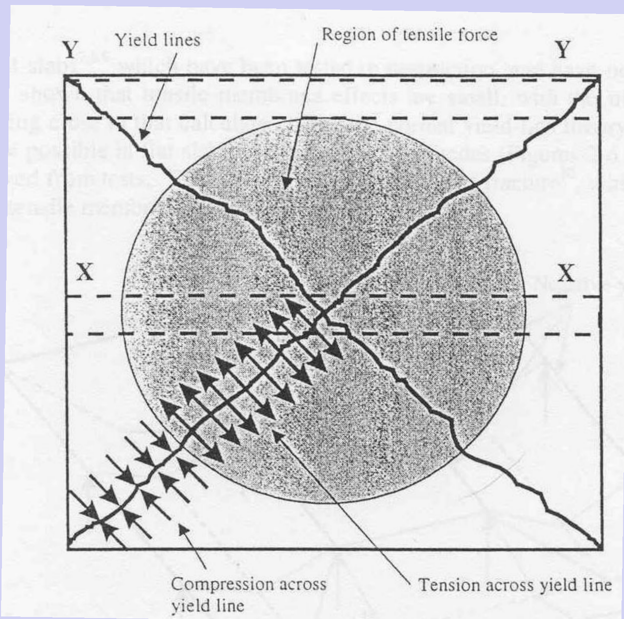
`PRNNXSHELL`

N_x, N_y, N_{xy} [in kN/m] + N_1, N_2 and α (with respect to the local axis *x*)
in the 4 integr. pts in the plane, for all shell elements

$$N_x = \int_{-t/2}^{t/2} \sigma_{xx}\, dt + \sum_{bars} \sigma_{x,i} A_i$$

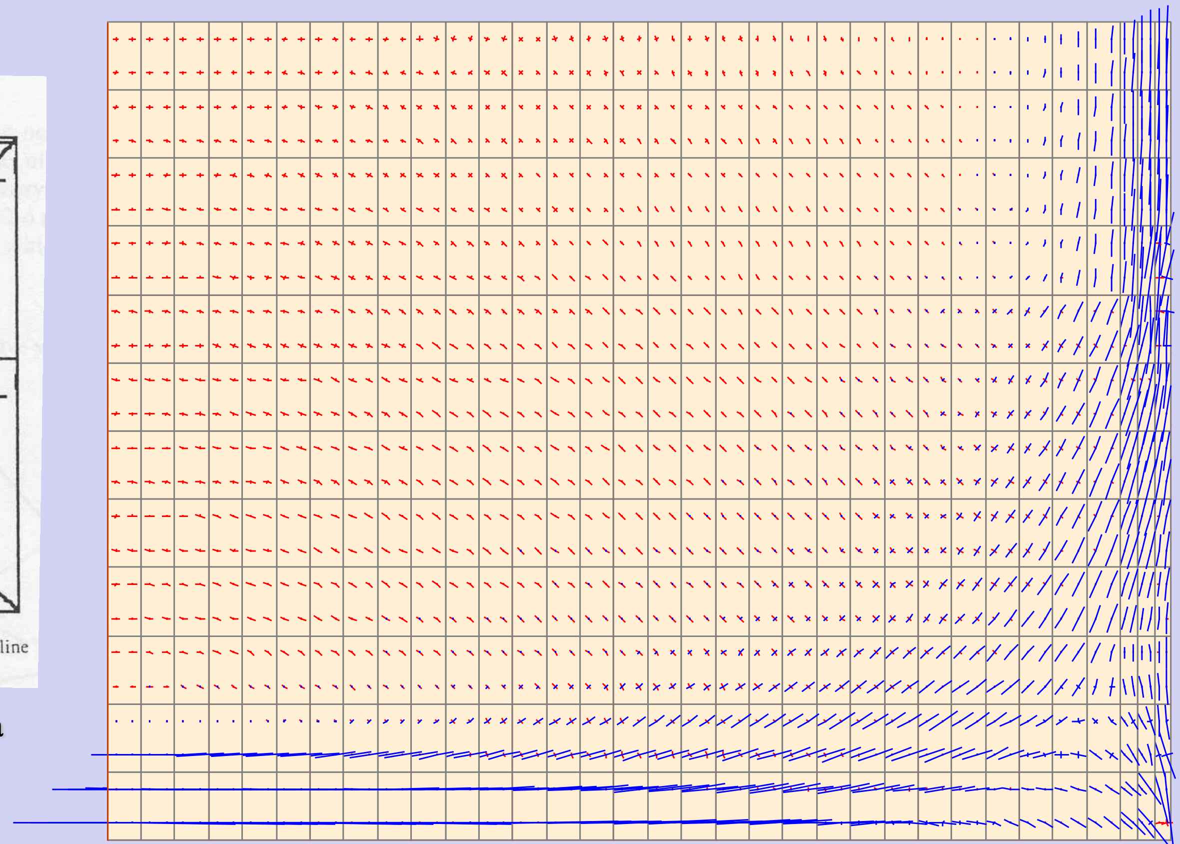
Membrane action in a concrete slab

Membrane stresses



In-plane membranes forces in a slab with no in-plane restraint

C. Bailey (2000)



SHELL:	1	Surf:	1	Nx:	2.12	Ny:	18.83	Nxy:	-0.72	N1:	18.86	N2:	2.09	angle:	-87.5°
SHELL:	1	Surf:	2	Nx:	2.32	Ny:	19.54	Nxy:	-0.92	N1:	19.59	N2:	2.27	angle:	-86.9°
SHELL:	1	Surf:	3	Nx:	-0.81	Ny:	18.01	Nxy:	-0.80	N1:	18.04	N2:	-0.85	angle:	-87.6°
SHELL:	1	Surf:	4	Nx:	-0.62	Ny:	18.71	Nxy:	-1.00	N1:	18.77	N2:	-0.67	angle:	-87.0°
SHELL:	2	Surf:	1	Nx:	2.31	Ny:	20.33	Nxy:	-1.75	N1:	20.49	N2:	2.15	angle:	-84.5°
SHELL:	2	Surf:	2	Nx:	2.78	Ny:	21.97	Nxy:	-2.97	N1:	22.42	N2:	2.33	angle:	-81.4°
SHELL:	2	Surf:	3	Nx:	-0.94	Ny:	19.42	Nxy:	-1.86	N1:	19.58	N2:	-1.11	angle:	-84.8°
SHELL:	2	Surf:	4	Nx:	-0.48	Ny:	21.06	Nxy:	-3.08	N1:	21.49	N2:	-0.91	angle:	-82.0°

What can be printed about the material behaviour?

PRNMXSHELL

M_x, M_y, M_{xy} [in kNm/m] + M_1, M_2 and α
in the 4 integr. pts in the plane, for all shell elements

$$M_x = \int_{-t/2}^{t/2} \sigma_{xx}\, y\, dt + \sum_{bars} \sigma_{x,i}\, y_i A_i$$

SHELL:	1	Surf: 1	Mx:	0.00	My:	-0.01	Mxy:	0.00	M1:	0.00	M2:	-0.01	angle: -3.2°
SHELL:	1	Surf: 2	Mx:	0.00	My:	-0.01	Mxy:	0.00	M1:	0.00	M2:	-0.01	angle: -3.7°
SHELL:	1	Surf: 3	Mx:	0.00	My:	0.00	Mxy:	0.00	M1:	0.00	M2:	0.00	angle: -9.5°
SHELL:	1	Surf: 4	Mx:	0.00	My:	0.00	Mxy:	0.00	M1:	0.00	M2:	0.00	angle: -9.3°
SHELL:	2	Surf: 1	Mx:	0.00	My:	-0.01	Mxy:	0.00	M1:	0.00	M2:	-0.01	angle: -3.7°
SHELL:	2	Surf: 2	Mx:	0.00	My:	-0.01	Mxy:	0.00	M1:	0.00	M2:	-0.01	angle: -3.7°
SHELL:	2	Surf: 3	Mx:	0.00	My:	0.00	Mxy:	0.00	M1:	0.00	M2:	0.00	angle: -8.7°
SHELL:	2	Surf: 4	Mx:	0.00	My:	0.00	Mxy:	0.00	M1:	0.00	M2:	0.00	angle: -7.3°
SHELL:	3	Surf: 1	Mx:	-0.01	My:	-0.01	Mxy:	0.00	M1:	-0.01	M2:	-0.01	angle: -0.8°
SHELL:	3	Surf: 2	Mx:	-0.01	My:	-0.01	Mxy:	0.00	M1:	-0.01	M2:	-0.01	angle: 0.0°
SHELL:	3	Surf: 3	Mx:	0.00	My:	0.00	Mxy:	0.00	M1:	0.00	M2:	0.00	angle: -10.3°
SHELL:	3	Surf: 4	Mx:	0.00	My:	0.00	Mxy:	0.00	M1:	0.00	M2:	0.00	angle: -6.2°

What can be printed about the material behaviour?

PRNEASHELL

$$\frac{E\,t}{1-\nu^2}$$

EA_x, EA_y

in the 4 integr. pts in the plane, for all shell elements

PRNEISHELL

$$\frac{E\,t^3}{12\left(1-\nu^2\right)}$$

EI_x, EI_y

in the 4 integr. pts in the plane, for all shell elements

STIFFNESS IN THE SHELL ELEMENTS.

ELEM	NG	EAx	EAy	EIx	EIy
-	-	kN/m	kN/m	kNm^2/m	kNm^2/m
1	1	2438151.	2438151.	23.	23.
1	2	2438151.	2438151.	23.	23.
1	3	2438151.	2438151.	23.	23.
1	4	2438151.	2438151.	23.	23.
2	1	2438151.	2438151.	23.	23.
2	2	2438151.	2438151.	23.	23.
2	3	2438151.	2438151.	23.	23.
2	4	2438151.	2438151.	23.	23.