SSLL106 - Right pipe

Summary:

This test allows a simple checking of the right pipe sections in linear mechanics of the structures static. The model is linear.

For each modeling, 6 types of loading are applied at the end: a traction, 2 efforts cutting-edges, 2 bending moments and a torsion. One applies moreover one internal pressure, a linear force distributed and a thermal dilation.

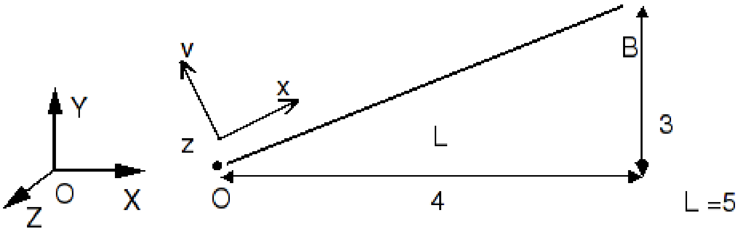
The values tested are displacements, the efforts with the nodes, and the constraints and deformations at the points of Gauss. The reference solution is analytical (RDM).

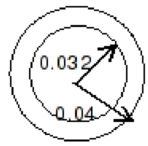
- Two modelings (A and B) make it possible to test the element `PIPE` with 3 modes of Fourier (modeling `TUYAU_3M`): modeling A uses `MECA_STATIQUE`, modeling B uses `STAT_NON_LINE` (elastic behavior).
- Two modelings (C and D) make it possible to test the element `PIPE` with 6 modes of Fourier (modeling `TUYAU_6M`).
- Two modelings (E and F) make it possible to test the element `PIPE` with 3 modes of Fourier and 4 nodes (modeling `TUYAU_3M`).

1 Problem of reference

1.1 Geometry

Right beam length L , of directing vector $(4,3,0)$.





Section of the pipe

Tubular section of external ray $a=0.04\text{m}$, of internal ray $b=0.032\text{m}$, thickness $e=0.008\,m$.

1.2 Material properties

The material used has an elastic behavior. The parameters materials take the following values:

- Young modulus $E=2.10^{11}\,Pa$,
- Poisson's ratio $\nu=0.3$,
- Density $\rho=7800\,kg/m^3$,
- Thermal dilation coefficient $\alpha=10^{-5}$.

1.3 Boundary conditions and loadings

- Embedding in O
- 6 elementary Loadings at the end B
  - in the reference mark (x,y,z) bound to the beam:
    $F_x=5.10^2\,N$ $M_x=5.10^2\,Nm$
    $F_y=5.10^2\,N$ $M_y=5.10^2\,Nm$
    $F_z=5.10^2\,N$ $M_z=5.10^2\,Nm$
  - maybe, in the total reference mark (X,Y,Z) :
    - 1 loading of traction: $F_X=4.10^2\,N$ and $F_Y=3.10^2\,N$
    - 2 efforts cutting-edges: in the plan (oxy) $F_X=-3.102\,N$ and $F_Y=4.10^2\,N$ and in the plan (oyz) $F_Z=5.10^2\,N$
    - 1 torque: $M_X=4.10^2\,Nm$ and $M_Y=3.10^2\,Nm$
    - 2 efforts cutting-edges: in the plan (oxy) $M_X=-3.10^2\,Nm$ and $M_Y=4.10^2\,Nm$ and in the plan (oyz) $M_Z=5.10^2\,Nm$
      - Internal pressure: $P=10^7\,Pa$
      - Gravity, with $g=10\text{m}/s^2$, in the direction $-Z$
      - Linear loading, $Fz=-141.146\,N/m$ (what corresponds to the load due to gravity: $Fz=mg$)
      - Thermal dilation: $Temp=100\,°C$

1.4 Notation of the characteristics of cross sections

The geometrical characteristics of the cross sections are noted:

- S : surface of the section
- I_y, I_z : geometrical moments of inertia compared to the main axes of inertia of the section
- J_x : constant of torsion

2 Reference solution

2.1 Method of calculating used for the reference solution

Analytical solution [bib1]: displacements in B in the reference mark $(Oxyz)$ bound to the beam.

Simple traction : $u_x=\frac{F_x L}{E S}$

Pure bending : $u_y=\frac{F_y L^3}{3 E I_z}$ $\theta_z=\frac{L^2 F_y}{2 E I_z}$

Pure bending : $u_z=\frac{F_z L^3}{3 E I_y}$ $\theta_y=\frac{-L^2 F_z}{2 E I_y}$

Torsion : $\theta_x=\frac{M_x L}{G J_x}$

Pure inflection : $u_z=\frac{-M_y L^2}{2 E I_y}$ $\theta_y=\frac{M_y L}{E I_y}$

Pure inflection : $u_y=\frac{M_z L^2}{2 E I_z}$ $\theta_z=\frac{M_z L}{E I_z}$

Pressure : $u_r=\frac{P a^2 r}{E(b^2-a^2)}\left[(1-\nu)+(1+\nu)\frac{b^2}{r^2}\right]$ calculated in $r=\frac{a+b}{2}$

in fact $u_r \in [7.12\mathrm{E}\text{-}06, 7.78\mathrm{E}\text{-}06]$ for $r \in [b, a]$

Here, the values are obtained with:

$S=1.809557\mathrm{E}\text{-}03\,m^2$ $I_y=I_z=1.18707\mathrm{E}\text{-}06\,m^4$ $J_x=2.37414\mathrm{E}\text{-}06\,m^4$ $L=5\,m$

For the generalized deformations of beam, one obtains, by the law of behavior:

Simple traction : $\epsilon_x=\frac{F_x}{E S}$

Pure bending : $\gamma_{xy}=\frac{F_y}{G S}$ $\kappa_z=\frac{F_y(L-x)}{E I_z}$

Pure bending : $\gamma_{xz}=\frac{F_z}{G S}$ $\kappa_y=\frac{F_z(L-x)}{E I_y}$

Torsion : $\kappa_x=\frac{M_x}{G J_x}$

Pure inflection : $\kappa_y=\frac{M_y}{E I_y}$

Pure inflection : $\kappa_z=\frac{M_z}{E I_z}$

Loading of gravity and linear loading:

If p indicate the distributed load, the moment in the beginning is worth: $M(o)=\frac{p L^2}{2}$ and of following displacement z at the end B is worth: $u_z(B)=\frac{p L^4}{8 E I}$.

The thermal loading of dilation led to an axial displacement (in the local direction x):

$U_x(B)=L(\alpha T)$

The deformations of free dilation of the surface of the pipe are simply, in local reference mark:

$$\epsilon_{xx}=\epsilon_{yy}=\alpha T$$

Finally to validate the calculation of the matrix of mass, a modal analysis of the first 12 clean modes (with embedding in O) must give, for the modes of inflection:

$$f_i=\left(\frac{\lambda_i}{L}\right)^2\sqrt{\frac{EI}{\rho S}}$$

Mode	λ_i	Frequency
1	1.87510407	2.9030234
2	4.69409113	18.192937
3	7.85475744	50.9407506
4	10.9955407	99.8235399
5	14.1371684	165.015464
6	17.2787596	246.504532
7	20.4203522	344.291453
8	23.5619449	458.376195
9	26.7035376	588.758758
10	29.8451302	735.43914
11	32.9867229	898.417343
12	36.1283155	1077.69337

2.2 Results of reference

- Displacement at the point B , efforts, constraints and deformations in the vicinity of the point O .
- Deformation generalized.
- Eigen frequencies

2.3 Uncertainty on the solution

Analytical solution.

2.4 Bibliographical references

1. Handbook of validation, test SSLL102 fixed Beam subjected to unit efforts [V3.01.102]

3 Modeling A

3.1 Characteristics of modeling

10 elements PIPE.

3.2 Characteristics of the grid

10 meshs SEG3. The beam is directed according to the vector $(4,3,0)$.

3.3 Remarks on the contents of the fields

Fields at the points of Gauss for the element PIPE , EPSI_ELGA and SIEF_ELGA, who provide the deformations and the constraints at the points of integration in the local reference mark of the element, are organized in the following way:
The values are stored:

- for each point of Gauss in the length, $(n=1,3)$
  - for each point of integration in the thickness, $(n=1,2\mathrm{N}_{COU}+1=7)$
    - for each point of integration on the circumference, $(n=1,2\mathrm{N}_{SECT}+1=33)$
      - 6 components of strain or stresses:
        EPXX EPYY EPZZ EPXY EPXZ EPYZ or
        SIXX SIYY SIZZ SIXY SIXZ SIYZ

where X indicate the direction given by the two nodes tops of the element, Y represent the angle ϕ describing the circumference and Z represent the ray. EPZZ and EPYZ correspond to ϵ_{rr}, $\epsilon_{r\phi}$ in the case as of deformations and SIZZ and SIYZ correspondent with σ_{rr}, $\sigma_{r\phi}$ in the case of the constraints are taken equal to zero.
For MECA_STATIQUE or MACRO_ELAS_MULT , the number of layers is fixed, and equal to 3, and the number of sectors is equal to 16.
EFGE_ELNO represent the efforts generalized with the 3 nodes in the classical way: NR, VY, VZ, MT, MFY, MFZ .

3.4 Sizes tested and Results of modeling A

Loading case	Size	Reference	% difference
$F_X = 4.0E+02$	DX	5.53E-06	– 0.04
$F_Y = 3.00E+02$	DY	4.14E-06	– 0.04
$F_X = -3.0E+02$	DRZ	2.63E-02	– 0.04
$F_Y = 4.0E+02$	DX	– 5.27E-02	– 0,056
	DY	7.02E-02	– 0,056
$F_Z = 5.0E+02$	DRX	1.58E-02	– 0.04
	DRY MARTINI	– 2.11E-02	– 0,039
	DZ	8.78E-02	– 0,056
$M_X = 4.0E+02$	DRX	1.10E-02	0
$M_Y = 3.0E+02$	DRY MARTINI	8.21E-03	0
$M_X = -3.0E+02$	DRX	– 6.32E-03	– 0.04
$M_Y = 4.0E+02$	DRY MARTINI	8.42E-03	– 0.04
	DZ	– 2.63E-02	– 0.04
$M_Z = 5.0E+02$	DRZ	1.05E-02	– 0,039
	DX	– 1.58E-02	– 0.04
	DY	2.11E-02	– 0,039
7: pressure	WO	7.38E-06	– 2,946
8: gravity	DZ	– 4.646E-02	0.09
9: distributed load	DZ	– 4.646E-02	0.09

Case of load	Field	Mesh	Not	Component	Reference	% difference
1	EFGE_ELNO	*M18*	1	NR	5.00E+02	0,136
1	EPSI_ELGA	*M18*	1	EPXX	1.38E-06	– 0,031
1	SIEF_ELGA	*M18*	1	SIXX	2.76E+05	– 1,159
4	EFGE_ELNO	*M18*	1	MT	5.00E+02	0
4	EPSI_ELGA	*M18*	1	EPXY	– 8.77E-05	– 0,102
4	EPSI_ELGA	*M18*	693	EPXY	– 1.09E-04	0,049
4	SIEF_ELGA	*M18*	1	SIXY	– 6.75E+06	– 0,159
4	SIEF_ELGA	*M18*	693	SIXY	– 8.42E+06	0,049
5	EFGE_ELNO	*M18*	1	MFY	5.00E+02	0,123
5	EPSI_ELGA	*M18*	479	EPXX	6.74E-05	– 0,046
5	SIEF_ELGA	*M18*	479	SIXX	1.35E+07	– 1,288
6	EFGE_ELNO	*M18*	1	MFZ	5.00E+02	0,123
6	EPSI_ELGA	*M18*	471	EPXX	6.74E-05	– 0,046
6	SIEF_ELGA	*M18*	471	SIXX	1.35E+07	– 1,288
7	EPSI_ELGA	*M18*	1	EPYY	2.28E-04	– 1,716
7	EPSI_ELGA	*M18*	693	EPYY	1.78E-04	0,741
7	SIEF_ELGA	*M18*	1	SIYY	4.56E+07	– 0,641
7	SIEF_ELGA	*M18*	693	SIYY	3.56E+07	– 0,371
8	EFGE_ELNO	*M1*	1	MFY	1764.3	2
9	EFGE_ELNO	*M1*	1	MFY	1764.3	2

Generalized deformations DEGE_ELNO :

Case of load	Loadings	Size	Reference	% difference
1	$F_X=4E+02$	EPXX	1.38155E-06	– 0.04
	$F_Y=3E+02$			
2	$F_X=-3E+02$	GAXY	3.5920E-06	32.0
	$F_Y=4E+02$	KZ	1.0530E-02	– 1.2
3	$F_Z=5E+02$	GAXZ	3.5920E-06	32
		KY	– 1.0530E-02	– 1.2
4	$M_X=4E+02$	GAT	2.73783E-03	0
	$M_Y=3E+02$			
5	$M_X=-3E+02$	KY	2.1060E-03	– 0.04
	$M_Y=4E+02$			
6	$M_Z=5E+02$	KZ	2.1060E-03	– 0.04

Eigen frequency	Reference	% difference
1	2.90229	0.05
2	2.90229	0.05
3	18.18967	0.08
4	18.18967	0.08
5	50.99367	0.02
6	50.99367	0.02
7	99.81783	0.2
8	99.81783	0.2
9	157.0190	0,001
10	164.9922	0.3
11	164.9922	0.3
12	253,185	2

3.5 Remarks

The values of shearings corresponding to the shearing action are not precise for this modeling. This is due to the functions of interpolation of order 2 of this element, for displacements of beam and rotations of beams. As transverse shearings of beam are obtained by: $\gamma_{xy}=\theta_z-\frac{du_y}{dx}$, and that for the pure bending, rotations vary like polynomials of order 2, but displacements, like polynomials of order 3, which is badly approached by the functions of interpolation. The derivative of displacements is thus not precise.

4 Modeling B

4.1 Characteristics of modeling

10 elements PIPE, calculation with STAT_NON_LINE.

4.2 Characteristics of the grid

10 meshs SEG3. The beam is directed according to the vector (4, 3.0).

4.3 Notice on the contents of the fields

Stress fields at the points of Gauss for the element PIPE , SIEF_ELGA, in the local reference mark of the element, are organized in the following way:
The values are stored:

- for each point of Gauss in the length, $(n=1,3)$
  - for each point of integration in the thickness, $(n=1,2\mathrm{N}_{COU}+1)$
    - for each point of integration on the circumference, $(n=1,2\mathrm{N}_{SECT}+1)$
      - 6 components of strain or stresses:
        EPXX EPYY EPZZ EPXY EPXZ EPYZ or
        SIXX SIYY SIZZ SIXY SIXZ SIYZ

where X indicate the direction given by the two nodes tops of the element, Y represent the angle ϕ describing the circumference and Z represent the ray. EPZZ and EPYZ correspond to ϵ_{rr}, $\epsilon_{r\phi}$ in the case of deformations and SIZZ and SIYZ correspondent with σ_{rr}, $\sigma_{r\phi}$ in the case of the constraints are taken equal to zero.
In STAT_NON_LINE , the number of layers is variable, as well as the number of sectors. One uses here 3 layers and 16 sectors by analogy with modeling A).

4.4 Sizes tested and results of modeling B

Loading case	Size	Reference	% difference
1	DX	5.53E-06	– 0.04
1	DY	4.14E-06	– 0.04
2	DRZ	2.63E-02	– 0.04
2	DX	– 5.27E-02	– 0,056
2	DY	7.02E-02	– 0,056
3	DRX	1.58E-02	– 0.04
3	DRY MARTINI	– 2.11E-02	– 0,039
3	DZ	8.78E-02	– 0,056
4	DRX	1.10E-02	0
4	DRY MARTINI	8.21E-03	0
5	DRX	– 6.32E-03	– 0.04
5	DRY MARTINI	8.42E-03	– 0.04
5	DZ	– 2.63E-02	– 0.04
6	DRZ	1.05E-02	– 0,039
6	DX	– 1.58E-02	– 0.04
6	DY	2.11E-02	– 0,039
7	WO	7.38E-06	– 2,946

Case of load	Field	Mesh	Not	Component	Reference	% difference
1	SIEF_ELGA	M18	Z	SIXX	2.76E+05	– 1,159
1	EFGE_ELNO	M18	1	NR	5.00E+02	0,136
4	SIEF_ELGA	M18	1	SIXY	– 6.75E+06	– 0,159
4	SIEF_ELGA	M18	693	SIXY	– 8.42E+06	0,049
4	EFGE_ELNO	M18	1	MT	5.00E+02	0
5	SIEF_ELGA	M18	479	SIXX	1.35E+07	– 1,288
5	EFGE_ELNO	M18	1	MFY	5.00E+02	0,123
6	SIEF_ELGA	M18	471	SIXX	1.35E+07	– 1,288
6	EFGE_ELNO	M18	1	MFZ	5.00E+02	0,123
7	SIEF_ELGA	M18	1	SIYY	4.56E+07	– 0,641
7	SIEF_ELGA	M18	693	SIYY	3.56E+07	– 0,371

Generalized deformations DEGE_ELNO :

Case of load	Loadings	Size	Reference	% difference
1	$F_X = 4E+02$	EPXX	1.38155E-06	– 0.04
	$F_Y = 3E+02$			
2	$F_X = -3E+02$	GAXY	3.5920E-06	32.0
	$F_Y = 4E+02$	KZ	1.0530E-02	– 1.2
3	$F_Z = 5E+02$	GAXZ	3.5920E-06	32
		KY	– 1.0530E-02	– 1.2
4	$M_X = 4E+02$	GAT	2.73783E-03	0
	$M_Y = 3E+02$			
5	$M_X = -3E+02$	KY	2.1060E-03	– 0.04
	$M_Y = 4E+02$			
6	$M_Z = 5E+02$	KZ	2.1060E-03	– 0.04

4.5 Remarks

The values of shearings corresponding to the shearing action are not precise for this modeling. This is due to the functions of interpolation of order 2 of this element, for displacements of beam and rotations of beams. As transverse shearings of beam are obtained by: $\gamma_{xy} = \theta_z - \frac{du_y}{dx}$, and that for the pure bending, rotations vary like polynomials of order 2, but displacements, like polynomials of order 3, which is badly approached by the functions of interpolation. The derivative of displacements is thus not precise.

5 Modeling C

5.1 Characteristics of modeling

10 elements TUYAU_6M.

5.2 Characteristics of the grid

10 meshs SEG3. The beam is directed according to the vector (4, 3.0).

5.3 Notice on the contents of the fields

Fields at the points of Gauss for the element PIPE , EPSI_ELGA and SIEF_ELGA, who provide the deformations and the constraints at the points of integration in the local reference mark of the element, are organized in the following way:
The values are stored:

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  - for each point of integration in the thickness, $(n=1,2\mathrm{N}_{COU}+1=7)$
    - for each point of integration on the circumference, $(n=1,2\mathrm{N}_{SECT}+1=33)$
      - 6 components of strain or stresses:
        EPXX EPYY EPZZ EPXY EPXZ EPYZ or
        SIXX SIYY SIZZ SIXY SIXZ SIYZ

where X indicate the direction given by the two nodes tops of the element, Y represent the angle ϕ describing the circumference and Z represent the ray. EPZZ and EPYZ correspondent with ϵ_{rr} , $\epsilon_{r\phi}$ in the case as of deformations and SIZZ and SIYZ correspondent with σ_{rr} , $\sigma_{r\phi}$ in the case of the constraints are taken equal to zero.
For MECA_STATIQUE or MACRO_ELAS_MULT , the number of layers is fixed, and equal to 3, and the number of sectors is equal to 16.
EFGE_ELNO represent the efforts generalize with the 3 nodes in the classical way: NR, VY, VZ, MT, MFY, MFZ .

5.4 Sizes tested and results of modeling C

	Loading case	Size	Reference	% difference
1	$F_X=4\mathrm{E}{+}02$	DX	5.53E-06	– 0.04
1	$F_Y=3\mathrm{E}{+}02$	DY	4.14E-06	– 0.04
2	$F_X=-3\mathrm{E}{+}02$	DRZ	2.63E-02	– 0.04
2	$F_Y=4\mathrm{E}{+}02$	DX	– 5.27E-02	– 0,056
2		DY	7.02E-02	– 0,056
3	$F_Z=5\mathrm{E}{+}02$	DRX	1.58E-02	– 0.04
3		DRY MARTINI	– 2.11E-02	– 0,039
3		DZ	8.78E-02	– 0,056
4	$M_X=4\mathrm{E}{+}02$	DRX	1.10E-02	0
4	$M_Y=3\mathrm{E}{+}02$	DRY MARTINI	8.21E-03	0
5	$M_X=-3\mathrm{E}{+}02$	DRX	– 6.32E-03	– 0.04
5	$M_Y=4\mathrm{E}{+}02$	DRY MARTINI	8.42E-03	– 0.04
5		DZ	– 2.63E-02	– 0.04
6	$M_Z=5\mathrm{E}{+}02$	DRZ	1.05E-02	– 0,039
6		DX	– 1.58E-02	– 0.04
6		DY	2.11E-02	– 0,039
	7: pressure	WO	7.38E-06	– 2,946
	8: gravity	DZ	– 4,646 E-02	0.09
	9: distributed load	DZ	– 4,646 E-02	0.09

Case of load	Field	Mesh	Not	Component	Reference	% difference
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4	EFGE_ELNO	M18	1	MT	5.00E+02	0
4	EPSI_ELGA	M18	1	EPXY	– 8.77E-05	– 0,102
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4	SIEF_ELGA	M18	1	SIXY	– 6.75E+06	– 0,159
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7	SIEF_ELGA	M18	1	SIYY	4.56E+07	– 0,641
7	SIEF_ELGA	M18	693	SIYY	3.56E+07	– 0,371
8	EFGE_ELNO	M1	1	MFY	1764.3	2
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Generalized deformations DEGE_ELNO :

Loading case	Loadings	Size	Reference	% difference
1	$F_X = 4.10^2$	EPXX	1.38155E-06	– 0.04
	$F_Y = 3.10^2$			
2	$F_X = -3.10^2$	GAXY	3.5920E-06	32
	$F_Y = 4.10^2$	KZ	1.0530E-02	– 1.2
3	$F_Z = 5.10^2$	GAXZ	3.5920E-06	32
		KY	– 1.0530E-02	– 1.2
4	$M_X = 4.10^2$	GAT	2.73783E-03	0
	$M_Y = 3.10^2$			
5	$M_X = -3.10^2$	KY	2.1060E-03	– 0.04
	$M_Y = 4.10^2$			
6	$M_Z = 5\ 10^2$	KZ	2.1060E-03	– 0.04

Eigen frequency	Reference	% difference
1	2.90229	0.05
2	2.90229	0.05
3	18.18967	0.08
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6	50.99367	0.02
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5.5 Remarks

The values of shearings corresponding to the shearing action are not precise for this modeling. This is due to the functions of interpolation of order 2 of this element, for displacements of beam and rotations of beams. As transverse shearings of beam are obtained by: $\gamma_{xy}=\theta_z-\frac{du_y}{dx}$, and that for the pure bending, rotations vary like polynomials of order 2, but displacements, like polynomials of order 3, which is badly approached by the functions of interpolation. The derivative of displacements is thus not precise.

6 Modeling D

6.1 Characteristics of modeling

10 elements TUYAU_6M, calculation with STAT_NON_LINE.

6.2 Characteristics of the grid

10 meshs SEG3. The beam is directed according to the vector (4, 3.0).

6.3 Notice on the contents of the fields

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for each point of integration in the thickness, $(n=1,2\mathrm{N}_{COU}+1)$

for each point of integration on the circumference, $(n=1,2\mathrm{N}_{SECT}+1)$

6 components of strain or stresses:

EPXX EPYY EPZZ EPXY EPXZ EPYZ or

SIXX SIYY SIZZ SIXY SIXZ SIYZ

where X indicate the direction given by the two nodes tops of the element, Y represent the angle ϕ describing the circumference and Z represent the ray. EPZZ and EPYZ correspondent with ϵ_{rr}, $\epsilon_{r\phi}$ in the case as of deformations and SIZZ and SIYZ correspondent with σ_{rr}, $\sigma_{r\phi}$ in the case as of constraints are taken equal to zero.
In STAT_NON_LINE , the number of layers is variable, as well as the number of sectors. One uses here 3 layers and 16 sectors by analogy with modeling A.

6.4 Sizes tested and results of modeling D

Loading case	Size	Reference	% difference
1	DX	5.53E-06	– 0.04
1	DY	4.14E-06	– 0.04
2	DRZ	2.63E-02	– 0.04
2	DX	– 5.27E-02	– 0,056
2	DY	7.02E-02	– 0,056
3	DRX	1.58E-02	– 0.04
3	DRY MARTINI	– 2.11E-02	– 0,039
3	DZ	8.78E-02	– 0,056
4	DRX	1.10E-02	0
4	DRY MARTINI	8.21E-03	0
5	DRX	– 6.32E-03	– 0.04
5	DRY MARTINI	8.42E-03	– 0.04
5	DZ	– 2.63E-02	– 0.04
6	DRZ	1.05E-02	– 0,039
6	DX	– 1.58E-02	– 0.04
6	DY	2.11E-02	– 0,039
7	WO	7.38E-06	– 2,946

Case of load	Field	Mesh	Not	Component	Reference	% difference
1	SIEF_ELGA	M18	Z	SIXX	2.76E+05	– 1,159
1	EFGE_ELNO	M18	1	NR	5.00E+02	0,136
4	SIEF_ELGA	M18	1	SIXY	– 6.75E+06	– 0,159
4	SIEF_ELGA	M18	693	SIXY	– 8.42E+06	0,049
4	EFGE_ELNO	M18	1	MT	5.00E+02	0
5	SIEF_ELGA	M18	479	SIXX	1.35E+07	– 1,288
5	EFGE_ELNO	M18	1	MFY	5.00E+02	0,123
6	SIEF_ELGA	M18	471	SIXX	1.35E+07	– 1,288
6	EFGE_ELNO	M18	1	MFZ	5.00E+02	0,123
7	SIEF_ELGA	M18	1	SIYY	4.56E+07	– 0,641
7	SIEF_ELGA	M18	693	SIYY	3.56E+07	– 0,371

Generalized deformations DEGE_ELNO :

Loading case	Loadings	Size	Reference	% difference
1	$F_X = 4.10^2$	EPXX	1.38155E-06	– 0.04
	$F_Y = 3.10^2$			
2	$F_X = -3.10^2$	GAXY	3.5920E-06	32
	$F_Y = 4.10^2$	KZ	1.0530E-02	– 1.2
3	$F_Z = 5.10^2$	GAXZ	3.5920E-06	32
		KY	-1.0530E-02	– 1.2
4	$M_X = 4.10^2$	GAT	2.73783E-03	0
	$M_Y = 3.10^2$			
5	$M_X = -3.10^2$	KY	2.1060E-03	– 0.04
	$M_Y = 4.10^2$			
6	$M_Z = 5\ 10^2$	KZ	2.1060E-03	– 0.04

6.5 Remarks

The values of shearings corresponding to the shearing action are not precise for this modeling. This is due to the functions of interpolation of order 2 of this element, for displacements of beam and rotations of beams. As transverse shearings of beam are obtained by: $\gamma_{xy}=\theta_z-\frac{du_y}{dx}$, and that for the pure bending, rotations vary like polynomials of order 2, but displacements, like polynomials of order 3, which is badly approached by the functions of interpolation. The derivative of displacements is thus not precise.

7 Modeling E

7.1 Characteristics of modeling

8 elements PIPE with 3 modes of Fourier and 4 nodes

7.2 Characteristics of the grid

8 meshs SEG4. The beam is directed according to the vector (4, 3.0).

7.3 Notice on the contents of the fields

Fields at the points of Gauss for the element PIPE , EPSI_ELGA and SIEF_ELGA, who provide the deformations and the constraints at the points of integration in the local reference mark of the element, are organized in the following way:
The values are stored:

- for each point of Gauss in the length, $(n=1,3)$
  - for each point of integration in the thickness, $(n=1,2\mathrm{N}_{COU}+1=7)$
    - for each point of integration on the circumference, $(n=1,2\mathrm{N}_{SECT}+1=33)$
      - 6 components of strain or stresses:
        EPXX EPYY EPZZ EPXY EPXZ EPYZ or
        SIXX SIYY SIZZ SIXY SIXZ SIYZ

where X indicate the direction given by the two nodes tops of the element, Y represent the angle ϕ describing the circumference and Z represent the ray. EPZZ and EPYZ correspondent with ϵ_{rr}, $\epsilon_{r\phi}$ in the case of deformations and SIZZ and SIYZ correspondent with σ_{rr}, $\sigma_{r\phi}$ in the case of the constraints are taken equal to zero.
For MECA_STATIQUE or MACRO_ELAS_MULT , the number of layers is fixed, and equal to 3, and the number of sectors is equal to 16.
EFGE_ELNO represent the efforts generalize with the 3 nodes in the classical way: NR, VY, VZ, MT, MFY, MFZ .

7.4 Sizes tested and results of modeling E

Loading case	Size	Reference	% difference
$F_X=4\text{E+02}$	DX	5.53E-06	– 0.04
$F_Y=3\text{E+02}$	DY	4.14E-06	– 0.04
$F_X=-3\text{E+02}$	DRZ	2.63E-02	– 0.04
$F_Y=4\text{E+02}$	DX	– 5.27E-02	– 0.02
	DY	7.02E-02	– 0.02
$F_Z=5\text{E+02}$	DRX	1.58E-02	– 0.04
	DRY MARTINI	– 2.11E-02	– 0.04
	DZ	8.78E-02	– 0.02
$M_X=4\text{E+02}$	DRX	1.10E-02	0
$M_Y=3\text{E+02}$	DRY MARTINI	8.21E-03	0
$M_X=-3\text{E+02}$	DRX	– 6.32E-03	– 0.04
$M_Y=4\text{E+02}$	DRY MARTINI	8.42E-03	– 0.04
	DZ	– 2.63E-02	– 0.04
$M_Z=5\text{E+02}$	DRZ	1.05E-02	– 0,039
	DX	– 1.58E-02	– 0.04
	DY	2.11E-02	– 0,039
7: pressure	WO	7.38E-06	– 2,946
8: gravity	DZ	– 4,646 E-02	0.04
9: distributed load	DZ	– 4,646 E-02	0.04

Case of load	Field	Mesh	Not	Component	Reference	% difference
1	EFGE_ELNO	*M18*	1	NR	5.00E+02	0,136
1	EPSI_ELGA	*M18*	1	EPXX	1.38E-06	– 0,031
1	SIEF_ELGA	*M18*	1	SIXX	2.76E+05	– 1,159
4	EFGE_ELNO	*M18*	1	MT	5.00E+02	0
4	EPSI_ELGA	*M18*	1	EPXY	– 8.77E-05	– 0,102
4	EPSI_ELGA	*M18*	693	EPXY	– 1.09E-04	0,049
4	SIEF_ELGA	*M18*	1	SIXY	– 6.75E+06	– 0,159
4	SIEF_ELGA	*M18*	693	SIXY	– 8.42E+06	0,049
5	EFGE_ELNO	*M18*	1	MFY	5.00E+02	0,123
5	EPSI_ELGA	*M18*	479	EPXX	6.74E-05	– 0,046
5	SIEF_ELGA	*M18*	479	SIXX	1.35E+07	– 1,288
6	EFGE_ELNO	*M18*	1	MFZ	5.00E+02	0,123
6	EPSI_ELGA	*M18*	471	EPXX	6.74E-05	– 0,046
6	SIEF_ELGA	*M18*	471	SIXX	1.35E+07	– 1,288
7	EPSI_ELGA	*M18*	1	EPYY	2.28E-04	– 1,716
7	EPSI_ELGA	*M18*	693	EPYY	1.78E-04	0,741
7	SIEF_ELGA	*M18*	1	SIYY	4.56E+07	– 0,641
7	SIEF_ELGA	*M18*	693	SIYY	3.56E+07	– 0,371
8	EFGE_ELNO	*M1*	1	MFY	1764.3	0.2
9	EFGE_ELNO	*M1*	1	MFY	1764.3	0.2

Generalized deformations DEGE_ELNO :

Case of load	Loadings	Size	Reference	% difference
1	$F_X=4E+02$	EPXX	1.38155E-06	– 0.04
	$F_Y=3E+02$			
2	$F_X=-3E+02$	GAXY	3.5920E-06	1.1
	$F_Y=4E+02$	KZ	1.0530E-02	– 0.05
3	$F_Z=5E+02$	GAXZ	3.5920E-06	1.1
		KY	– 1.0530E-02	– 0.05
4	$M_X=4E+02$	GAT	2.73783E-03	0
	$M_Y=3E+02$			
5	$M_X=-3E+02$	KY	2.1060E-03	– 0.04
	$M_Y=4E+02$			
6	$M_Z=5E+02$	KZ	2.1060E-03	– 0.04

Eigen frequency	Reference	% difference
1	2.90229	0.02
2	2.90229	0.02
3	18.18967	0.1
4	18.18967	0.1
5	50.99367	0.4
6	50.99367	0.4
7	99.81783	0.6
8	99.81783	0.6
9	157.0190	0,001

7.5 Remarks

The values of shearings corresponding to the shearing action are precise for this modeling. This is due to the functions of interpolation of order 3 of this element, for displacements of beam and rotations of beams.

8 Modeling F

8.1 Characteristics of modeling

1 elements TUYAU_3M with 4 nodes, calculation with STAT_NON_LINE.

8.2 Characteristics of the grid

1 meshs SEG4. The beam is directed according to the vector (4, 3.0).

8.3 Notice on the contents of the fields

Stress fields at the points of Gauss for the element PIPE , SIEF_ELGA, in the local reference mark of the element, are organized in the following way:
The values are stored:
for each point of Gauss in the length, $(n=1,3)$
for each point of integration in the thickness, $(n=1,2\mathrm{N}_{COU}+1)$
for each point of integration on the circumference, $(n=1,2\mathrm{N}_{SECT}+1)$
6 components of strain or stresses:
EPXX EPYY EPZZ EPXY EPXZ EPYZ or
SIXX SIYY SIZZ SIXY SIXZ SIYZ
where X indicate the direction given by the two nodes tops of the element, Y represent the angle ϕ describing the circumference and Z represent the ray. EPZZ and EPYZ correspondent with ϵ_{rr}, $\epsilon_{r\phi}$ in the case of deformations and SIZZ and SIYZ correspondent with σ_{rr}, $\sigma_{r\phi}$ in the case as of constraints are taken equal to zero.
In STAT_NON_LINE , the number of layers is variable, as well as the number of sectors. One uses here 3 layers and 16 sectors by analogy with modeling A.

8.4 Sizes tested and results of modeling F

Loading case	Size	Reference	% difference
1	DX	5.53E-06	– 0.04
1	DY	4.14E-06	– 0.04
2	DRZ	2.63E-02	– 0.04
2	DX	– 5.27E-02	– 0.02
2	DY	7.02E-02	– 0.02
3	DRX	1.58E-02	– 0.04
3	DRY MARTINI	– 2.11E-02	– 0.02
3	DZ	8.78E-02	– 0.04
4	DRX	1.10E-02	0
4	DRY MARTINI	8.21E-03	0
5	DRX	– 6.32E-03	– 0.04
5	DRY MARTINI	8.42E-03	– 0.04
5	DZ	– 2.63E-02	– 0.04
6	DRZ	1.05E-02	– 0.04
6	DX	– 1.58E-02	– 0.04
6	DY	2.11E-02	– 0.04
7	WO	7.38E-06	– 3.3

Case of load	Field	Mesh	Not	Component	Reference	% difference
1	SIEF_ELGA	M18	Z	SIXX	2.76E+05	– 1,159
1	EFGE_ELNO	M18	1	NR	5.00E+02	0,136
4	SIEF_ELGA	M18	1	SIXY	– 6.75E+06	– 0,159
4	SIEF_ELGA	M18	693	SIXY	– 8.42E+06	0,049
4	EFGE_ELNO	M18	1	MT	5.00E+02	0
5	SIEF_ELGA	M18	479	SIXX	1.35E+07	– 1,288
5	EFGE_ELNO	M18	1	MFY	5.00E+02	0,123
6	SIEF_ELGA	M18	471	SIXX	1.35E+07	– 1,288
6	EFGE_ELNO	M18	1	MFZ	5.00E+02	0,123
7	SIEF_ELGA	M18	1	SIYY	4.56E+07	– 0,641
7	SIEF_ELGA	M18	693	SIYY	3.56E+07	– 0,371

Generalized deformations DEGE_ELNO :

Loading case	Loadings	Size	Reference	% difference
1	$F_X = 4.10^2$	$EPXX$	1.38155E-06	– 0.04
	$F_Y = 3.10^2$			
2	$F_X = -3.10^2$	$GAXY$	3.5920E-06	21
	$F_Y = 4.10^2$	KZ	1.0530E-02	– 0.04
3	$F_Z = 5.10^2$	$GAXZ$	3.5920E-06	21
		KY	– 1.0530E-02	– 0.04
4	$M_X = 4.10^2$	GAT	2.73783E-03	0
	$M_Y = 3.10^2$			
5	$M_X = -3.10^2$	KY	2.1060E-03	– 0.04
	$M_Y = 4.10^2$			
6	$M_Z = 510^2$	KZ	2.1060E-03	– 0.04

8.5 Remarks

The values of shearings corresponding to the shearing action are not precise for this modeling. This is due to the weak discretization for this modeling (only one element).

9 Summary of the results

This test makes it possible to check the good performance of the element PIPE (3 modes and 6 modes of Fourier) in linear elasticity, with the operators MECA_STATIQUE and STAT_NON_LINE, for the whole of the loadings applicable to this element.

The variations compared to the analytical reference solution (solution in assumption of beam) are very weak for displacements (0.04% to 0.06%), except for the loading of pressure where the variation of 3% is due to the fact that Wo represent an average radial displacement. Actually this radial displacement varies in the thickness. The variation on the strains and the stresses $(\approx 1\%)$ is more important than that on displacements but remains acceptable taking into account the fact that these values are calculated into cubes points of integration located in the thickness of the pipe.