SSLL106 - Pipe Summarized

right:

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

For each modelization, 6 types of loading are applied at the end: a tension, 2 shears, 2 bending moments and a torsion. One applies moreover one internal pressure, a linear force distributed and a thermal thermal expansion.

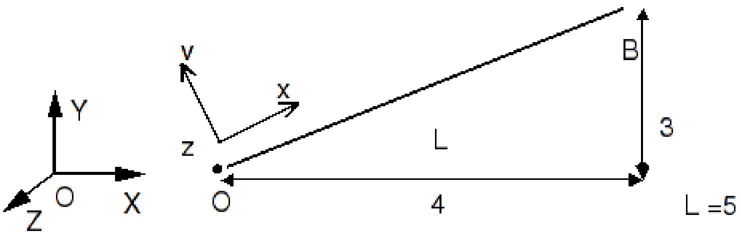
The values tested are displacements, the forces with the nodes, and the forced and strains with Gauss points. The reference solution is analytical (RDM).

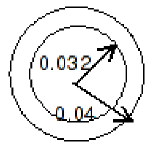
- Two modelizations (A and B) make it possible to test the element `PIPE` with 3 modes of Fourier (modelization `TUYAU_3M`): the modelization A uses `MECA_STATIQUE`, the modelization B uses `STAT_NON_LINE` (elastic behavior).
- Two modelizations (C and D) make it possible to test the element `PIPE` with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

1 Problem of reference

1.1 Geometry

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





Section of the tubular

pipe Section of external radius $a=0.04\mathrm{m}$, internal radius $b=0.032\mathrm{m}$, thickness $e=0.008\,m$.

1.2 Material properties

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

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

1.3 Boundary conditions and loadings

- Fixed support in O
- 6 elementary Loadings at the end B
  - in the reference (x,y,z) related to 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 (X,Y,Z) :
    - 1 loading of tension: $F_X=4.10^2\,N$ and $F_Y=3.10^2\,N$
    - 2 shears: in the plane (oxy) $F_X=-3.102\,N$ and $F_Y=4.10^2\,N$ the plane (oyz) $F_Z=5.10^2\,N$
    - 1 twisting moment: $M_X=4.10^2\,Nm$ and $M_Y=3.10^2\,Nm$
    - 2 shears: in the plane (oxy) $M_X=-3.10^2\,Nm$ and $M_Y=4.10^2\,Nm$ the plane (oyz) $M_Z=5.10^2\,Nm$
      - Internal pressure: $P=10^7\,Pa$
      - Gravity, with $g=10\mathrm{m}/s^2$, in the direction $-Z$
      - Linear loading, $Fz=-141.146\,N/m$ (what corresponds to the load due to gravity: $Fz=mg$)
      - Thermal thermal expansion: $Temp=100\,°C$

1.4 Notation of the characteristics of cross sections

the geometrical characteristics of the cross sections are noted:

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

2 Reference solution

2.1 Method of calculating used for the analytical reference solution

Solution [bib1]: displacements in B the reference $(Oxyz)$ related to the beam.

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

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

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

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

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

Here, the values are obtained with:
$S=1.809557\text{E-}03\,m^2$ $I_y=I_z=1.18707\text{E-}06\,m^4$ $J_x=2.37414\text{E-}06\,m^4$ $L=5\,m$

For the generalized strains of beam, one obtains, by the constitutive law:

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

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 bending : $\kappa_y=\frac{M_y}{E I_y}$

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

Loading of gravity and linear loading:

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

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

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

The strains of free thermal expansion of the surface of the pipe are simply, in local coordinate system:

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

Finally to validate the computation of the mass matrix, a modal analysis of the first 12 eigen modes (with fixed support in O) must give, for the modes of bending:

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

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 , forces, stresses and strains in the vicinity of the point O .
- Strain generalized.
- Eigenfrequencies

2.3 Uncertainty on the analytical

solution Solution.

2.4 Bibliographical references

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

3 Modelization A

3.1 Characteristic of the modelization

10 elements PIPE.

3.2 Characteristics of the mesh

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

3.3 Remarks on the contents of the fields

the fields to Gauss points for the element PIPE, EPSI_ELGA and SIEF_ELGA, which provide the strains and the forced to the points of integration in the local coordinate system of the element, are organized in the following way:
The values are stored:

- for each Gauss point in the length, $(n=1,3)$
  - 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 indicates the direction given by the two nodes tops of the element, Y represents the angle ϕ describing the circumference and Z represents the radius. EPZZ and EPYZ correspond to ϵ_{rr}, $\epsilon_{r\phi}$ in the case as of strains and SIZZ and SIYZ corresponding to σ_{rr}, $\sigma_{r\phi}$ in the case as of stresses are taken equal to zero.
For MECA_STATIQUE or MACRO_ELAS_MULT , the number of layers is built-in, and equal to 3, and the number of sectors is equal to 16.
EFGE_ELNO represents the forces generalized with the 3 nodes in the classical way: N, VY, VZ, MT, MFY, MFZ .

3.4 Quantities tested and Results of the modelization A

Loading case	Quantity	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	– 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	8.21E-03	0
$M_X=-3.0E+02$	DRX	– 6.32E-03	– 0.04
$M_Y=4.0E+02$	DRY	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: charge distributed	DZ	– 4.646E-02	0.09

Field	Loading case	Does not net		Component	Reference	% difference
1	EFGE_ELNO	$M18$	1	N	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

Strains generalized DEGE_ELNO :

Loading cases	Loadings	Quantity	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

Eigenfrequency	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 the shears corresponding to the shears are not precise for this modelization. This is due to the interpolation functions of order 2 of this element, for displacements of beam and the rotations of beams. As the transverse shears 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 interpolation functions. The derivative of displacements is thus not precise.

4 Modelization B

4.1 Characteristic of the modelization

10 elements PIPE, computation with STAT_NON_LINE.

4.2 Characteristics of the mesh

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

4.3 Notice on the contents of the fields

the stress fields to Gauss points for the element PIPE , SIEF_ELGA, in the local coordinate system of the element, are organized in the following way:
The values are stored:

- for each Gauss point in the length, $(n=1,3)$
  - 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 indicates the direction given by the two nodes tops of the element, Y represents the angle ϕ describing the circumference and Z represents the radius. EPZZ and EPYZ correspond to ϵ_{rr}, $\epsilon_{r\phi}$ in the case as of strains and SIZZ and SIYZ corresponding to σ_{rr}, $\sigma_{r\phi}$ in the case as of stresses 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 the modelization A).

4.4 Quantities tested and results of the modelization B

Loading case	Quantity	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	– 2.11E-02	– 0.039
3	DZ	8.78E-02	– 0.056
4	DRX	1.10E-02	0
4	DRY	8.21E-03	0
5	DRX	– 6.32E-03	– 0.04
5	DRY	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

Field	Loading cases	Does not net		Component	Reference	% difference
1	SIEF_ELGA	M18	Z	SIXX	2.76E+05	– 1.159
1	EFGE_ELNO	M18	1	N	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 Strains DEGE_ELNO :

Loading cases	Loadings	Quantity	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 the shears corresponding to the shears are not precise for this modelization. This is due to the interpolation functions of order 2 of this element, for displacements of beam and the rotations of beams. As the transverse shears 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 interpolation functions. The derivative of displacements is thus not precise.

5 Modelization C

5.1 Characteristic of the modelization

10 elements TUYAU_6M.

5.2 Characteristics of the mesh

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

5.3 Notice on the contents of the fields

the fields to Gauss points for the element PIPE, EPSI_ELGA and SIEF_ELGA, which provide the strains and the forced to the points of integration in the local coordinate system of the element, are organized in the following way:
The values are stored:
- for each Gauss point in the length, $(n=1,3)$
  - 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 indicates the direction given by the two nodes tops of the element, Y represents the angle ϕ describing the circumference and Z represents the radius. EPZZ and EPYZ corresponding to ϵ_{rr}, $\epsilon_{r\phi}$ in the case as of strains and SIZZ and SIYZ corresponding to σ_{rr}, $\sigma_{r\phi}$ in the case as of stresses are taken equal to zero.
For MECA_STATIQUE or MACRO_ELAS_MULT , the number of layers is built-in, and equal to 3, and the number of sectors is equal to 16.
EFGE_ELNO represents the forces generalize with the 3 nodes in the classical way: N, VY, VZ, MT, MFY, MFZ .

5.4 Quantities tested and results of the modelization C

	Loading case	Quantity	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	– 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	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	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: charge distributed	DZ	– 4.646 E-02	0.09

Field	Loading case	Does not net		Component	Reference	% difference
1	EFGE_ELNO	M18	1	N	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
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5	SIEF_ELGA	M18	479	SIXX	1.35E+07	– 1.288
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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 Strains DEGE_ELNO :

Loading case	Loadings	Quantity	Reference	% difference
1	FX = 4.102	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

Eigenfrequency	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

5.5 Remarks

the values of the shears corresponding to the shears are not precise for this modelization. This is due to the interpolation functions of order 2 of this element, for displacements of beam and the rotations of beams. As the transverse shears 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 interpolation functions. The derivative of displacements is thus not precise.

6 Modelization D

6.1 Characteristic of the modelization

10 elements TUYAU_6M, computation with STAT_NON_LINE.

6.2 Characteristics of the mesh

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

6.3 Notice on the contents of the fields

the stress fields to Gauss points for the element PIPE , SIEF_ELGA, in the local coordinate system of the element, are organized in the following way:
The values are stored:

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

where X indicates the direction given by the two nodes tops of the element, Y represents the angle ϕ describing the circumference and Z represents the radius. EPZZ and EPYZ corresponding to ϵ_{rr} , $\epsilon_{r\phi}$ in the case as of strains and SIZZ and SIYZ corresponding to σ_{rr} , $\sigma_{r\phi}$ in the case as of stresses are taken equal to zero.
In STAT_NON_LINE , the number of layers is variable, as well as the number of sectors. 3 layers here are used and 16 sectors by analogy with modelization A.

6.4 Grandeurs tested and results of the modelization D

Loading case	Quantity	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	– 2.11E-02	– 0.039
3	DZ	8.78E-02	– 0.056
4	DRX	1.10E-02	0
4	DRY	8.21E-03	0
5	DRX	– 6.32E-03	– 0.04
5	DRY	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

Field	Loading cases	Nets	Not	Component	Reference	% difference
1	SIEF_ELGA	M18	Z	SIXX	2.76E+05	– 1.159
1	EFGE_ELNO	M18	1	N	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 Strains DEGE_ELNO :

Loading case	Loadings	Quantity	Reference	% difference
1	FX = 4.102	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 the shears corresponding to the shears are not precise for this modelization. This is due to the interpolation functions of order 2 of this element, for displacements of beam and the rotations of beams. As the transverse shears 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 interpolation functions. The derivative of displacements is thus not precise.

7 Modelization E

7.1 Characteristic of the modelization

8 elements `PIPE` with 3 modes of Fourier and 4 nodes

7.2 Characteristic of the mesh

8 meshes `SEG4`. The beam is directed according to the vector (4, 3,0).

7.3 Notice on the contents of the fields

the fields to Gauss points for the element `PIPE` , `EPSI_ELGA` and `SIEF_ELGA`, which provide the strains and the forced to the points of integration in the local coordinate system of the element, are organized in the following way:

The values are stored:

- for each Gauss point in the length, $(n=1,3)$
  - 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 indicates the direction given by the two nodes tops of the element, Y represents the angle ϕ describing the circumference and Z represents the radius. `EPZZ` and `EPYZ` corresponding to ϵ_{rr} , $\epsilon_{r\phi}$ in the case as of strains and `SIZZ` and `SIYZ` corresponding to σ_{rr} , $\sigma_{r\phi}$ in the case as of stresses are taken equal to zero.

For `MECA_STATIQUE` or `MACRO_ELAS_MULT` , the number of layers is built-in, and equal to 3, and the number of sectors is equal to 16.

`EFGE_ELNO` represents the forces generalize with the 3 nodes in the classical way: `N, VY, VZ, MT, MFY, MFZ` .

7.4 Quantities tested and results of the modelization E

Loading case	Quantity	Reference	% difference
$F_X=4E+02$	DX	5.53E-06	– 0.04
$F_Y=3E+02$	DY	4.14E-06	– 0.04
$F_X=-3E+02$	DRZ	2.63E-02	– 0.04
$F_Y=4E+02$	DX	– 5.27E-02	– 0.02
	DY	7.02E-02	– 0.02
$F_Z=5E+02$	DRX	1.58E-02	– 0.04
	DRY	– 2.11E-02	– 0.04
	DZ	8.78E-02	– 0.02
$M_X=4E+02$	DRX	1.10E-02	0
$M_Y=3E+02$	DRY	8.21E-03	0
$M_X=-3E+02$	DRX	– 6.32E-03	– 0.04
$M_Y=4E+02$	DRY	8.42E-03	– 0.04
	DZ	– 2.63E-02	– 0.04
$M_Z=5E+02$	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: charge distributed	DZ	– 4.646 E-02	0.04

Field	Loading case	Does not net		Component	Reference	% difference
1	EFGE_ELNO	$M18$	1	N	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 Strains `DEGE_ELNO` :

Loading cases	Loadings	Quantity	Reference	% difference
1	$F_X = 4\text{E+02}$	`EPXX`	1.38155E-06	– 0.04
	$F_Y = 3\text{E+02}$			
2	$F_X = -3\text{E+02}$	`GAXY`	3.5920E-06	1.1
	$F_Y = 4\text{E+02}$	`KZ`	1.0530E-02	– 0.05
3	$F_Z = 5\text{E+02}$	`GAXZ`	3.5920E-06	1.1
		`KY`	– 1.0530E-02	– 0.05
4	$M_X = 4\text{E+02}$	`GAT`	2.73783E-03	0
	$M_Y = 3\text{E+02}$			
5	$M_X = -3\text{E+02}$	`KY`	2.1060E-03	– 0.04
	$M_Y = 4\text{E+02}$			
6	$M_Z = 5\text{E+02}$	`KZ`	2.1060E-03	– 0.04

Eigenfrequency	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 the shears corresponding to the shears are precise for this modelization. This is due to the interpolation functions of order 3 of this element, for displacements of beam and the rotations of beams.

8 Modelization F

8.1 Characteristic of modelization

1 elements TUYAU_3M with 4 nodes, computation with STAT_NON_LINE.

8.2 Characteristics of mesh

1 meshes SEG4. The beam is directed according to the vector (4, 3,0).

8.3 Notice on the contents of the fields

the stress fields to Gauss points for the element PIPE , SIEF_ELGA, in the local coordinate system of the element, are organized in the following way:
The values are stored:
for each Gauss point in the length, $(n=1,3)$
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 indicates the direction given by the two nodes tops of the element, Y represents the angle ϕ describing the circumference and Z represents the radius. EPZZ and EPYZ corresponding to ϵ_{rr}, $\epsilon_{r\phi}$ in the case as of strains and SIZZ and SIYZ corresponding to σ_{rr}, $\sigma_{r\phi}$ in the case as of stresses are taken equal to zero.
In STAT_NON_LINE , the number of layers is variable, as well as the number of sectors. 3 layers here are used and 16 sectors by analogy with modelization A.

8.4 Grandeurs tested and results of the modelization F

Loading case	Quantity	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	– 2.11E-02	– 0.02
3	DZ	8.78E-02	– 0.04
4	DRX	1.10E-02	0
4	DRY	8.21E-03	0
5	DRX	– 6.32E-03	– 0.04
5	DRY	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

Field	Loading cases	Nets	Not	Component	Reference	% difference
1	SIEF_ELGA	M18	Z	SIXX	2.76E+05	– 1.159
1	EFGE_ELNO	M18	1	N	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 Strains DEGE_ELNO :

Loading cases	Loadings	Quantity	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 the shears corresponding to the shears are not precise for this modelization. This is due to the weak discretization for this modelization (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 operators MECA_STATIQUE and STAT_NON_LINE, for all 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 represents an average radial displacement. Actually this radial displacement varies in the thickness. The variation on the strains and the forced $(\approx 1\%)$ 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.