SSLL101 - Pipework: Problem of Summarized

HOVGAARD:

It is about a linear elastic test, in static, of a noncoplanar three-dimensional pipework comprising elbows. There exists a test in dynamics of same structure (SDLX02) [V2.05.002].

One tests elements POU_D_T, POU_C_T, PIPE (SEG3 and SEG4) and TUYAU_6M (SEG3) via seven modelizations:

- modelization a: 92 elements POU_D_T (40 for an elbow), computation with MECA_STATIQUE,
- modelization b: 10 elements POU_D_T, 4 elements POU_C_T (2 for an elbow), computation with MECA_STATIQUE,
- modelization C: 28 elements PIPE (SEG3) (5 for an elbow), computation with MECA_STATIQUE,
- modelization D: 28 elements TUYAU_6M (SEG3) (5 for an elbow), computation with MECA_STATIQUE,
- modelization E: 28 elements PIPE (SEG4) (5 for an elbow), computation with MECA_STATIQUE,
- modelization F: 10 elements POU_D_T, 4 elements POU_C_T (2 for an elbow), computation with STAT_NON_LINE/COMP_ELAS,
- modelization G: 10 elements POU_D_T, 4 elements POU_C_T (2 for an elbow) computation with STAT_NON_LINE/COMP_INCR.

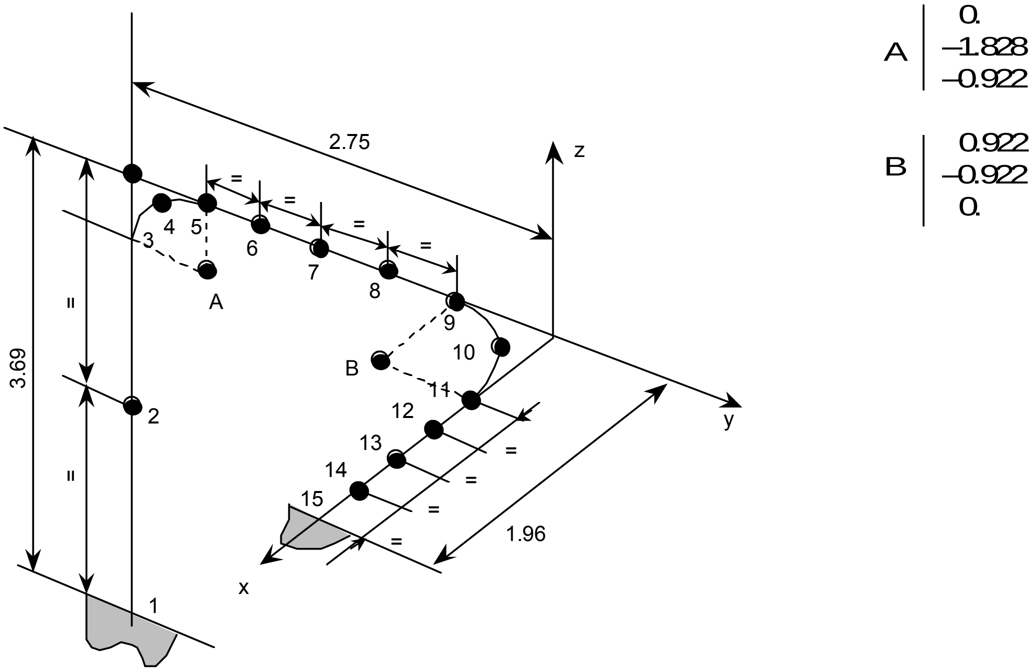
The loadings are of type:

- gravity,
- thermal,
- nodal forces.

1 Problem of reference

1.1 Geometry

geometry, as well as the points of modelization are represented on the following figure:



- diameter external of the pipe: $0.185\,m$
- thickness of the pipe: $6.12\,mm$
- radius of curvature of the elbows: $0.922\,m$
- pipework full of water

1.2 Material properties

$E = 1.658\,E+11\,Pa$

$\nu = 0.3$

$\rho = 13404.10\,kg/m^3$

$\alpha = 0.1288\,E-4/C°$

1.3 Boundary conditions and loadings

- embedded Items 1 and 15,
- Loading:
  1. Gravity according to $-z$,
  2. uniform Rise in temperature of $472.22\,C°$,
  3. nodal Forces.

Nodes	2	3	4 - 10	5 - 9	6 - 7 - 8	11	12/01/13	14
Fz (N)	– 624.897	– 788.724	– 327.654	– 214.839	– 102.5145	– 222.687	– 117.720	– 176.580

2 Reference solution

2.1 Method of calculating used for the reference solution

the reference solutions adopted to check the modelizations *Code_Aster* are the following ones:

- for the modelizations `BEAM`: comparison with the codes: POUX , ADL and TITUS-T [bib1], using a modelization of type beam,
- for the modelizations `PIPE` : comparison with the code ABAQUS , using a modelization of type pipe. The number of mode of Fourier (M) used during the computation of the reference is identical to that used during computations with *Code_Aster*.

2.2 Results of reference

Case of Loading	Displacement to item 3	Modelization Beam (POUX ADL , TITUS)	Modelization Pipe: $M=3$ (ABAQUS)	Modelization Pipe: $M=6$ (ABAQUS)
Inertia loading	DX	– 0.1658E-3	– 0.16517E-3	– 0.16512E-3
	DY	– 0.2040E-4	– 0.13870E-4	– 0.13946E-4
	DZ	– 0.8010E-5	– 0.80376E-5	– 0.80369E-5
nodal Force	DX	– 0.1651E-3	– 0.16445E-3	– 0.16441E-3
	DY	– 0.2080E-4	– 0.14245E-4	– 0.14320E-4
	DZ	– 0.9516E-5	– 0.10047E-4	– 0.10047E-4
Thermal expansion	DX	– 6.1418E-3	– 6.3277E-3	– 6.3236E-3
	DY	– 13.090E-3	– 13.092E-3	– 13.093E-3
	DZ	16.799E-3	16.798E-3	16.798E-3

2.3 Uncertainty on the solution

uncertainty on the reference solution is fixed at 2% .

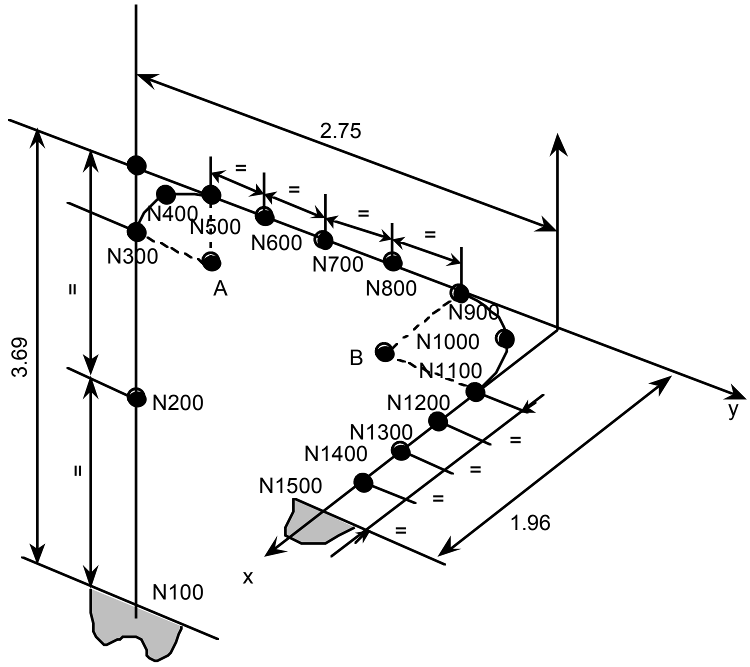
2.4 Bibliographical references

1.M.W. KELLOG Co. Design of Piping Systems. New York, 1956 - Problem n°5.9

3 Modelization A

3.1 Characteristic of the modelization

the curved elements are modelled by right elements.
A half curved element is modelled by 20 right elements.



Lengths in meters

3.2 Characteristic of the mesh

Many nodes: 93
Number of meshes and type: 92 POU_D_T

3.3 Quantities tested and results

Identification	Displacement		Reference beam	%
	N300	*DX*	– 0.1658E-3	0.0
Inertia loading		*DY*	– 0.2040E-4	0.02
		DZ	– 0.8010E-5	0.0
	N300	*DX*	– 0.1651E-3	0.04
nodal Force		*DY*	– 0.2080E-4	– 0.01
		DZ	– 0.9516E-5	0.004
	N300	*DX*	– 6.1418E-3	0.007
Thermal expansion		*DY*	– 13.090E-3	0.012
		DZ	16.799E-3	0.003

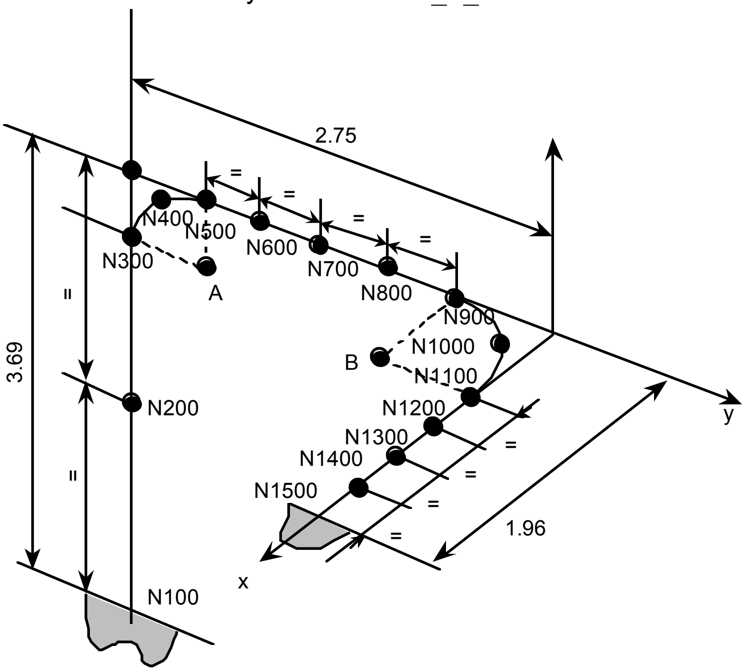
3.4 Remark

the differences between the Aster *results* and the reference solution beam are all lower than 0.04%

4 Modelization B

4.1 Characteristic of the modelization

the curved elements are modelled by elements POU_C_T.



Lengths in meters

4.2 Characteristic of the mesh

Many nodes: 15
Number of meshes and type: 10 POU_D_T
4 POU_C_T

4.3 Values tested

Identification	Displacement		Reference beam	%
	$N300$	DX	– 0.1658E-3	0.017
Inertia loading		DY	– 0.2040E-4	0.65
		DZ	– 0.8010E-5	– 0.006
	$N300$	DX	– 0.1651E-3	0.04
nodal Force		DY	– 0.2080E-4	0.02
		DZ	– 0.9516E-5	0.002
	$N300$	DX	– 6.1418E-3	– 0.02
Thermal expansion		DY	– 13.090E-3	0.005
		DZ	16.799E-3	0.003

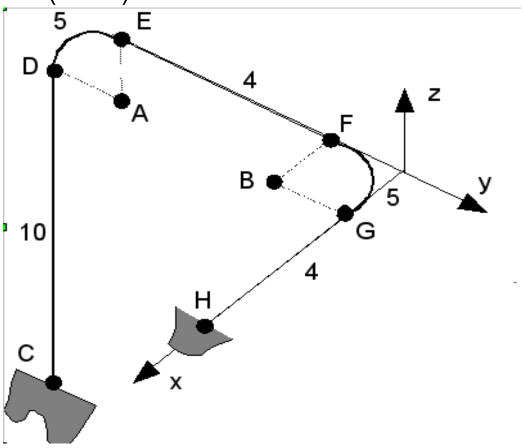
4.4 Remark

the differences between the Aster *results* and the results in reference beam are all lower than 0.02% except for DY in inertia loading where the variation is of 0.65%

5 Modelization C

5.1 Characteristic of the modelization

Modelization PIPE (SEG3)



Lengths in meters

Boundary conditions: points C and H

- DDL beam: $DX=DY=DZ=DRX=DRY=DRZ=0$
- DDL shell:
  - $UIm=VIm=WIm=0(m=2,3)$
  - $UOm=VOm=WOm=0(m=2,3)$
  - $WI1=WO1=WO=0$

5.2 Characteristics of the mesh

Many nodes:	57
Number of meshes and type:	28 SEG3

5.3 Values tested

Identification	Displacement	Reference pipe ($M=3$)	%
	Not D DX	– 0.16517E-3	– 0.93
Inertia loading	DY	– 0.13870E-4	– 9.80
	DZ	– 0.80376E-5	– 0.24
	Point D DX	– 0.16445E-3	– 0.94
nodal Force	DY	– 0.14245E-4	– 9.61
	DZ	– 0.10047E-4	– 0.20
	Point D DX	– 6.3277E-3	1.99
Thermal expansion	DY	– 13.092E-3	0.08
	DZ	16.798E-3	– 0.93

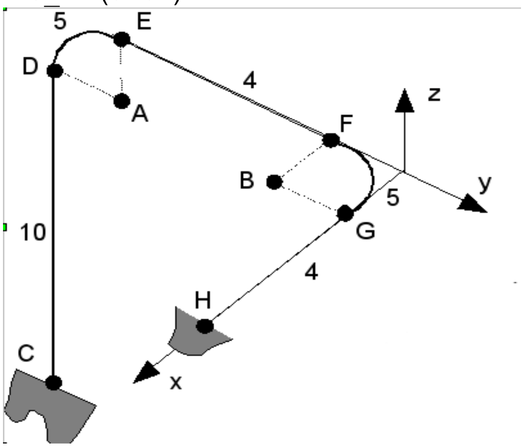
5.4 Remark

the results got with *Code_Aster* are similar to those of ABAQUS by elements pipes except for the displacement DY (inertia loading and nodal force) where the variation is about 10%.

6 Modelization D

6.1 Characteristic of the modelization

Modelization TUYAU_6M (SEG3)



Lengths in meters

Boundary conditions: points C and H

- DDL beam: $DX=DY=DZ=DRX=DRY=DRZ=0$
- DDL shell:
  - $UIm=VIm=WIm=0(m=2,6)$
  - $UOm=VOm=WOm=0(m=2,6)$
  - $WI1=WO1=WO=0$

6.2 Characteristics of the mesh

Many nodes:	57
Number of meshes and type:	28 SEG3

6.3 Quantities tested and results

Identification	Displacement		Reference pipe ($M=6$)	%
	Not D	DX	– 0.16512E-3	– 0.93
Inertia loading		DY	– 0.13946E-4	– 9.78
		DZ	– 0.80369E-5	– 0.24
	Point D	DX	– 0.16441E-3	– 0.94
nodal Force		DY	– 0.14320E-4	– 9.58
		DZ	– 0.10047E-4	– 0.21
	Point D	DX	– 6.3236E-3	1.99
Thermal expansion		DY	– 13.093E-3	0.08
		DZ	16.798E-3	0.49

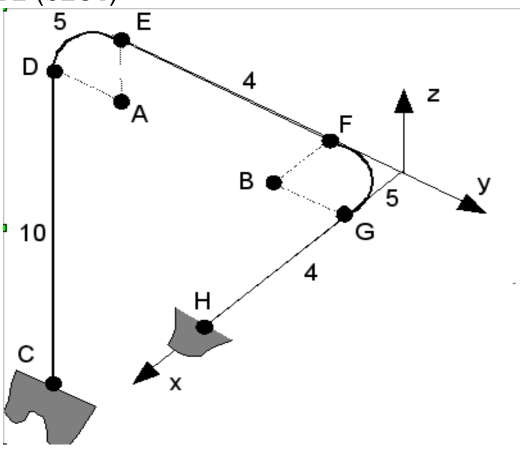
6.4 Remark

the results got with *Code_Aster* are similar to those of ABAQUS for elements pipes except for the displacement DY (inertia loading and nodal force) where the variation is about 10%.

7 Modelization E

7.1 Characteristic of the modelization

Modelization PIPE (SEG4)



Lengths in meters

Boundary conditions: points C and H

- DDL beam: $DX=DY=DZ=DRX=DRY=DRZ=0$
- DDL shell:
  - $UIm=VIm=WIm=0(m=2,3)$
  - $UOm=VOm=WOm=0(m=2,3)$
  - $WI1=WO1=WO=0$

7.2 Characteristics of the mesh

Many nodes:	85
Number of meshes and type:	28 SEG4

7.3 Quantities tested and results

Identification	Displacement		Reference pipe ($M=3$)	%
	Not D	DX	– 0.16517E-3	– 0.22
Inertia loading		DY	– 0.13870E-4	– 4.73
		DZ	– 0.80376E-5	– 0.18
	Point D	DX	– 0.16445E-3	– 0.37
nodal Force		DY	– 0.14245E-4	– 1.74
		DZ	– 0.10047E-4	– 0.50
	Point D	DX	– 6.3277E-3	0.02
Thermal expansion		DY	– 13.092E-3	0.10
		DZ	16.798E-3	0.27

7.4 Remarks

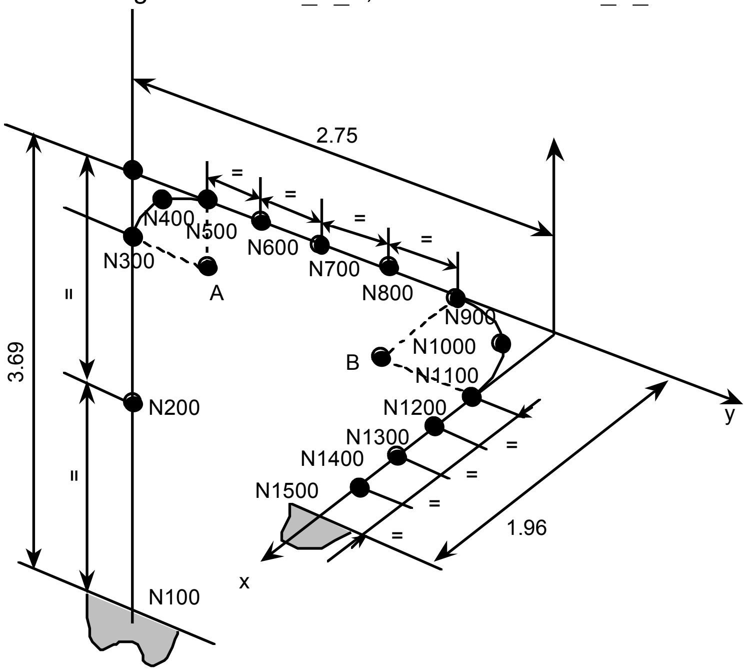
The mesh in SEG4 is obtained from a mesh SEG3 with command CREA_MAILLAGE, MODI_MAILLE with the option "SEG3_4". It is important that the medium node of the SEG3 is well in the medium, *the Code_Aster* checks this condition with a tolerance.

The results got with *Code_Aster* are similar to those of ABAQUS with elements pipes except for displacement DY (inertia loading and nodal force) or the variation is about 5% and 2%.

8 Modelization F

8.1 Characteristic of the modelization

Modelization straight beam `POU_D_T`, curved beam `POU_C_T`.



Lengths in meters

Boundary conditions: points C and H

- DDL beam: $DX = DY = DZ = DRX = DRY = DRZ = 0$

8.2 Characteristics of the mesh

Many nodes:	15
Number of meshes and type:	`10 POU_D_T`
	4 `POU_C_T, 2 per elbow`

8.3 Quantities tested and results

displacements are tested in several nodes, compared to the references obtained by the various codes $POUX$, ADL and $TITUS$.

Loading	Component of displacement	Node	Value of reference	Tolerance
Inertia loading	DX	N300	-1.65800E-04	0.10%
	DY	N300	-2.04000E-05	0.80%
	DZ	N300	-8.01000E-06	0.10%
	DX	N500	-2.39700E-04	0.10%
	DY	N500	1.77700E-04	0.10%
	DZ	N500	-2.68100E-04	0.10%
	DX	N700	-1.85500E-04	0.10%
	DY	N700	1.77500E-04	0.10%
	DZ	N700	-3.94000E-04	0.10%
	DX	N900	-1.27800E-04	0.10%
	DY	N900	1.77400E-04	0.10%
	DZ	N900	-4.97700E-04	0.10%
	DX	N1100	0.00000E+00	1.00E-03
	DY	N1100	5.68200E-05	0.10%
	DZ	N1100	-2.20700E-04	0.10%

Loading	Component of displacement	Node	Value of reference	Tolerance
Thermal expansion	DX	N300	-6.14180E-03	0.10%
	DY	N300	-1.30900E-02	0.10%
	DZ	N300	1.67990E-02	0.10%
	DX	N500	-1.03020E-02	0.10%
	DY	N500	-8.13200E-03	0.10%
	DZ	N500	1.97230E-02	0.10%
	DX	N700	-1.13700E-02	0.10%
	DY	N700	-5.38300E-03	0.10%
	DZ	N700	1.61350E-02	0.10%
	DX	N900	-1.22380E-02	0.10%
	DY	N900	-2.63300E-03	0.10%
	DZ	N900	1.22620E-02	0.10%
	DX	N1100	-6.30800E-03	0.10%
	DY	N1100	1.54200E-03	0.10%
	DZ	N1100	1.93100E-03	0.10%

Loading	Component of displacement	Node	Value of reference	Tolerance
Forces nodal	DX	N300	-1.65100E-04	0.10%
	DY	N300	-2.08000E-05	0.10%
	DZ	N300	-9.51600E-06	0.10%
	DX	N500	-2.38600E-04	0.10%
	DY	N500	1.77300E-04	0.10%
	DZ	N500	-2.69700E-04	0.10%
	DX	N700	-1.84800E-04	0.10%
	DY	N700	1.77100E-04	0.10%
	DZ	N700	-3.94800E-04	0.10%
	DX	N900	-1.27400E-04	0.10%
	DY	N900	1.77000E-04	0.10%
	DZ	N900	-4.96400E-04	0.10%
	DX	N1100	0.00000E+00	1.00E-03
	DY	N1100	5.67400E-05	0.10%
	DZ	N1100	-2.18600E-04	the 0.10%

forces are tested in several nodes, compared to the references obtained by the various codes $POUX$, ADL and $TITUS$.

Loading	Component of the force	Node	Value of reference	Tolerance
Inertia loading	N	N100	-2.27600E+03	0.50%
	VY	N100	-1.61100E+02	0.10%
	VZ	N100	-1.00950E+01	0.50%
	MT	N100	-5.34000E+01	0.10%
	MFY	N100	-8.96600E+01	0.10%
	MFZ	N100	-1.58500E+02	0.10%
	N	N1500	1.00950E+01	0.50%
	VY	N1500	-1.61100E+02	0.10%
	VZ	N1500	1.16500E+03	0.50%
	MT	N1500	1.56000E+01	0.50%
	MFY	N1500	1.26050E+03	0.50%
	MFZ	N1500	2.90100E+02	0.10%

Loading	Component of the force	Node	Value of reference	Tolerance
Thermal expansion	N	N100	-7.43100E+03	0.10%
	VY	N100	-7.61300E+03	0.10%
	VZ	N100	2.79100E+03	0.10%
	MT	N100	1.61500E+03	0.10%
	MFY	N100	-6.19300E+03	0.10%
	MFZ	N100	-1.47120E+04	0.10%
	N	N1500	-2.79100E+03	0.10%
	VY	N1500	-7.61300E+03	0.10%
	VZ	N1500	-7.43300E+03	0.10%
	MT	N1500	7.05200E+03	0.10%
	MFY	N1500	-1.04600E+04	0.10%
	MFZ	N1500	8.86200E+03	0.10%

Loading	Component of force	Node	Value of reference	Tolerance
Forces N	nodal	N100	-2.27300E+03	0.10%
	VY	N100	-1.61100E+02	0.10%
	VZ	N100	-9.81000E+00	0.10%
	MT	N100	-5.30200E+01	0.10%
	MFY	N100	-8.95300E+01	0.10%
	MFZ	N100	-1.58630E+02	0.10%
	N	N1500	9.81000E+00	0.10%
	VY	N1500	-1.61100E+02	0.10%
	VZ	N1500	1.16800E+03	0.10%
	MT	N1500	1.19000E+01	0.50%
	MFY	N1500	1.26100E+03	0.10%
	MFZ	N1500	2.89700E+02	0.10%

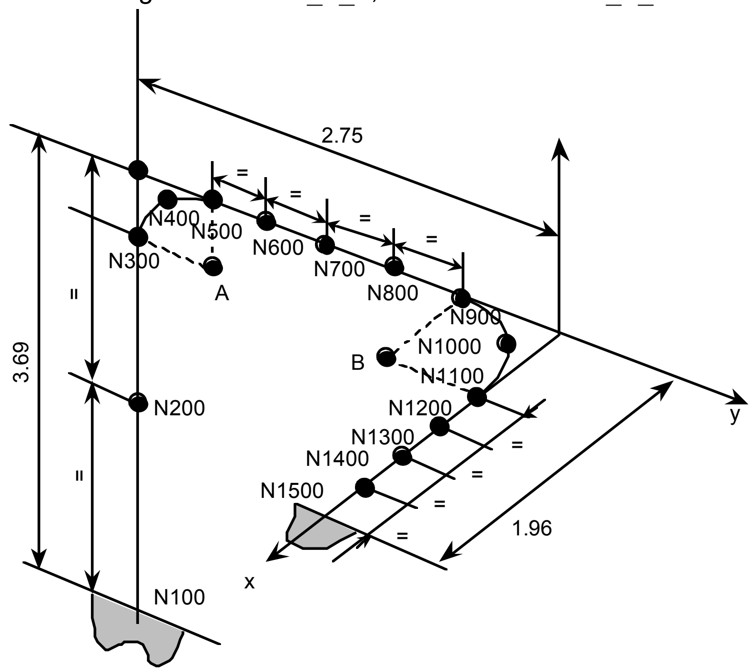
8.4 Remarks

the results got with *Code_Aster* are similar to those of the other codes with straight beams and curved beams. The maximum error is lower than 1% as well for displacements as for the forces.

9 Modelization G

9.1 Characteristic of the modelization

Modelization straight beam `POU_D_T`, curved beam `POU_C_T`.



Lengths in meters

Boundary conditions: points C and H

- DDL beam: $DX = DY = DZ = DRX = DRY = DRZ = 0$

9.2 Characteristics of the mesh

Many nodes: 15
Number of meshes and type: `10 POU_D_T`
4 `POU_C_T, 2 per elbow`

9.3 Quantity tested and results

displacements are tested in several nodes, compared to the references obtained by the various codes $POUX$, ADL and $TITUS$.

Loading	Component of displacement	Node	Value of reference	Tolerance
Inertia loading	DX	N300	-1.65800E-04	0.10%
	DY	N300	-2.04000E-05	0.80%
	DZ	N300	-8.01000E-06	0.10%
	DX	N500	-2.39700E-04	0.10%
	DY	N500	1.77700E-04	0.10%
	DZ	N500	-2.68100E-04	0.10%
	DX	N700	-1.85500E-04	0.10%
	DY	N700	1.77500E-04	0.10%
	DZ	N700	-3.94000E-04	0.10%
	DX	N900	-1.27800E-04	0.10%
	DY	N900	1.77400E-04	0.10%
	DZ	N900	-4.97700E-04	0.10%
	DX	N1100	0.00000E+00	0.10%
	DY	N1100	5.68200E-05	0.10%
	DZ	N1100	-2.20700E-04	0.10%

Loading	Component of displacement	Node	Value of reference	Tolerance
Thermal expansion	DX	N300	-6.14180E-03	0.10%
	DY	N300	-1.30900E-02	0.10%
	DZ	N300	1.67990E-02	0.10%
	DX	N500	-1.03020E-02	0.10%
	DY	N500	-8.13200E-03	0.10%
	DZ	N500	1.97230E-02	0.10%
	DX	N700	-1.13700E-02	0.10%
	DY	N700	-5.38300E-03	0.10%
	DZ	N700	1.61350E-02	0.10%
	DX	N900	-1.22380E-02	0.10%
	DY	N900	-2.63300E-03	0.10%
	DZ	N900	1.22620E-02	0.10%
	DX	N1100	-6.30800E-03	0.10%
	DY	N1100	1.54200E-03	0.10%
	DZ	N1100	1.93100E-03	0.10%

Loading	Component of displacement	Node	Value of reference	Tolerance
Forces nodal	DX	N300	-1.65100E-04	0.10%
	DY	N300	-2.08000E-05	0.10%
	DZ	N300	-9.51600E-06	0.10%
	DX	N500	-2.38600E-04	0.10%
	DY	N500	1.77300E-04	0.10%
	DZ	N500	-2.69700E-04	0.10%
	DX	N700	-1.84800E-04	0.10%
	DY	N700	1.77100E-04	0.10%
	DZ	N700	-3.94800E-04	0.10%
	DX	N900	-1.27400E-04	0.10%
	DY	N900	1.77000E-04	0.10%
	DZ	N900	-4.96400E-04	0.10%
	DX	N1100	0.00000E+00	0.10%
	DY	N1100	5.67400E-05	0.10%
	DZ	N1100	-2.18600E-04	the 0.10%

forces are tested in several nodes, compared to the references obtained by the various codes $POUX$, ADL and $TITUS$.

Loading	Component of the force	Node	Value of reference	Tolerance
Inertia loading	N	N100	-2.27600E+03	0.50%
	VY	N100	-1.61100E+02	0.10%
	VZ	N100	-1.00950E+01	0.50%
	MT	N100	-5.34000E+01	0.10%
	MFY	N100	-8.96600E+01	0.10%
	MFZ	N100	-1.58500E+02	0.10%
	N	N1500	1.00950E+01	0.50%
	VY	N1500	-1.61100E+02	0.10%
	VZ	N1500	1.16500E+03	0.50%
	MT	N1500	1.56000E+01	0.50%
	MFY	N1500	1.26050E+03	0.50%
	MFZ	N1500	2.90100E+02	0.10%

Loading	Component of the force	Node	Value of reference	Tolerance
Thermal expansion	N	N100	-7.43100E+03	0.10%
	VY	N100	-7.61300E+03	0.10%
	VZ	N100	2.79100E+03	0.10%
	MT	N100	1.61500E+03	0.10%
	MFY	N100	-6.19300E+03	0.10%
	MFZ	N100	-1.47120E+04	0.10%
	N	N1500	-2.79100E+03	0.10%
	VY	N1500	-7.61300E+03	0.10%
	VZ	N1500	-7.43300E+03	0.10%
	MT	N1500	7.05200E+03	0.10%
	MFY	N1500	-1.04600E+04	0.10%
	MFZ	N1500	8.86200E+03	0.10%

Loading	Component of force	Node	Value of reference	Tolerance
Forces N	nodal	N100	-2.27300E+03	0.10%
	VY	N100	-1.61100E+02	0.10%
	VZ	N100	-9.81000E+00	0.10%
	MT	N100	-5.30200E+01	0.10%
	MFY	N100	-8.95300E+01	0.10%
	MFZ	N100	-1.58630E+02	0.10%
	N	N1500	9.81000E+00	0.10%
	VY	N1500	-1.61100E+02	0.10%
	VZ	N1500	1.16800E+03	0.10%
	MT	N1500	1.19000E+01	0.50%
	MFY	N1500	1.26100E+03	0.10%
	MFZ	N1500	2.89700E+02	0.10%

9.4 Remarks

the results got with *Code_Aster* are similar to those of the other codes with straight beams and curved beams. The maximum error is lower than 1% as well for displacements as for the forces.

10 Summary of the Modelization

results beam:
The results are similar to the reference solution (modelization beam: average of results of 3 codes) as well for the modelization A, where each elbow is discretized by 20 right elements, POU_D_T, as for the modelization B, where one uses the elements curves POU_C_T. One simply notes, in this case, a variation a little more important in a value of displacement (0.65%).
Modelization pipe:
The Code_Aster *results* are similar to those of ABAQUS (for elements pipes), except for displacement DY and the loadings inertia loading and nodal forces where the variation with the reference solution is more important with meshes the SEG3 (10%) that with meshes the SEG4 (5%).

The thermal loading of thermal expansion gives similar results.
This benchmark makes it possible to test a noncoplanar pipework.