SSNL117 - Elbow in inflection in elastoplasticity

Summary:
This test validates the modeling of the phenomena of ovalization in pipings in the elastoplastic field with the elements PIPE: an elbow, prolonged by right pipes is subjected to an inflection in its plan. Piping is thick (of size similar to the elbows of the primary education circuits). The reference solution is digital: it is obtained with *Code_Aster* using a grid $3D$ elbow.

Two modelings make it possible to validate the elements PIPE (with right and bent elements with 3 nodes for modeling A and of the right and bent elements with 4 nodes for modeling B) in elastoplasticity.

Into modeling B, a term of “total” rotation, developed by EDF, ECA and FRAMATOME [bib2], for pipings under earthquake, is introduced via an macro-order Python.

1 Problem of reference

1.1 Geometry

Piping bent in the plan XY. The right parts have as a length $L=1\,m$.
The elbow has as a radius of curvature: $R_c=1.25\,m$

The tubular section has as an average radius $r_{moy}=395.5\,mm$ and for thickness $e=77\text{mm}$.

1.2 Properties of materials

The material is elastoplastic with isotropic linear work hardening.

$E=2.\text{E}11\,Pa$

$\nu=0.3$

Elastic limit $SIGY=200.10^6\,Pa$

Module of work hardening $\text{D\_SIGM\_EPSI}=2.10^{10}\,Pa$

1.3 Boundary conditions and loadings

Embedding in A (degrees of freedom of beam blocked, but free degrees of freedom of ovalization).
Moment MZ imposed in D growing:

Increment 1 $Mz=3086702.1520853\,Nm$

10 equal increments until:

Increment 11 $Mz=7091146.5935484\,Nm$

1.4 Initial conditions

Without object.

2 Reference solution

2.1 Method of calculating used for the reference solution

Comparison with other digital results got with *Code_Aster* (version 4.3 [bib1]) with a grid $3D$ elbow and right parts, connected at the ends with right beams. This grid $3D$ comprise 1024 meshs HEXA20. A modeling of the elbow in elements COQUE_3D gave results comparable to calculation $3D$ (see [§2.2]).
Modeling B uses it MFront behavior of the type ***Plasticity*** instead of behavior VMIS_ISOT_LINE of code_aster (reference calculation 3D).

Quantities are also calculated useful for the seismic behaviour using the following formulas:

$$EN=\varepsilon_{xx} \quad (1)$$

$$ET=\frac{r_{moy}\times\gamma_{torsion}}{2} \quad (2)$$

$$EFY=r_{moy}\times\kappa_y \text{ and } EFZ=r_{moy}\times\kappa_z \quad (3)$$

$$ESTAR=\sqrt{EN^2+ET^2+\left(\frac{\pi\times EFY}{4}\right)^2+\left(\frac{\pi\times EFZ}{4}\right)^2} \quad (4)$$

Calculation of the second type of quantities for the earthquake :

$$\lambda=\frac{e\times R_c}{r_{moy}^2} \quad (5)$$

and

$$k2=max\left(1,\frac{1{,}65}{\lambda}\right) \text{ and } \gamma_c=\frac{8}{9}\lambda^{-\frac{2}{3}} \text{ and } \gamma=max\left(1,\gamma_c\right) \quad (6)$$

With:

$$EFY_2=\frac{r_{moy}\times\kappa_y}{k2} \text{ and } EFZ_2=\frac{r_{moy}\times\kappa_z}{k2} \quad (7)$$

And:

$$ESTAR_2=\sqrt{EN^2+ET^2+\left(\frac{\pi\times\gamma\times EFY}{4}\right)^2+\left(\frac{\pi\times\gamma\times EFZ}{4}\right)^2} \quad (8)$$

2.2 Results of reference

For one moment applied Mz in D, displacement DY same point D is worth [bib1]:

Moment	Dy not D (m) (3D)	Dy not D (m) (COQUE_3D)
0.	0.	0.
3.08670D+06	1.09349D-02	1.08875D-02
3.48715D+06	1.23536D-02	
3.88759D+06	1.37891D-02	1.37381D-02
4.28804D+06	1.52727D-02	
4.68848D+06	1.68128D-02	
5.08892D+06	1.84085D-02	
5.48937D+06	2.01272D-02	
5.88981D+06	2.20836D-02	
6.29026D+06	2.43502D-02	
6.69070D+06	2.70438D-02	
7.09115D+06	3.04756D-02	

2.3 Precision on the results of reference

Owing to the fact that the reference solution is digital, one can evaluate the precision according to [§2.2] with 2% by comparison of the solutions 3D and COQUE_3D.

2.4 References bibliographical

[1] J.M. PROIX, A. BEN HAJ YEDDER: “Project CACIP: study of a piping bent in inflection”. Note EDF/DER HI-75/98/001/0
[2] C. CHURN (SEPTEN), MN. BERTON, NR. BLAY (ECA), F. LE BRETON (FRAMATOME - ANP): “Project of new coding of the criteria of seismic dimensioning of pipings”. Note EDF/SEPTEN E-N-ES-MS/01-01004-A.

3 Modeling A

3.1 Characteristics of modeling

The structure is with a grid in elements pipes (meshs SEG3, modeling PIPE).

3.2 Characteristics of the grid

20 meshs SEG3 (The grid is regular: 10 elements in the elbow, 5 in each right pipe)

3.3 Sizes tested and results

Increment of load	DY point D	Reference	% difference
1: $Mz=3.08670\mathrm{D}+06\mathrm{Nm}$	$DY\ (m)$	1.09349E-02	2.3
8: $Mz=5.88981\mathrm{D}+06\mathrm{Nm}$	$DY\ (m)$	2.20836E-02	2.75

4 Modeling B

4.1 Characteristics of modeling

The structure is with a grid in elements pipes with 4 nodes (meshs SEG4, modeling PIPE).

4.2 Characteristics of the grid

11 meshs SEG4 (5 elements in the elbow, 3 in each right pipe)

4.3 Calculation of the term of "Total" Rotation

This term of "total" rotation was developed within the framework of a tripartite action EDF - ECA - FRAMATOME [bib2], for a future integration in the code of dimensioning RCC-M.
It is expressed starting from rotations of two points representative of the elbow (entered and left), by:

$$R_G=\sqrt{\Delta R_x^2+\Delta R_y^2+\Delta R_z^2}$$

where

$$\Delta R_x=DRX_{sortiecoude}-DRX_{entréecoude}$$
$$\Delta R_y=DRY_{sortiecoude}-DRY_{entréecoude}$$
$$\Delta R_z=DRZ_{sortiecoude}-DRZ_{entréecoude}$$

This term is calculated by the macro-order Python MACR_ROTA_GLOBALE who is integrated in the body of the command file. The result of this macro-order is a function Aster of total rotation according to the moment. A test of not-regression comes to validate this function.

4.4 Sizes tested and results

TestS compared to calculation 3D for total rotation:

Moment	***Aster***	***Precision***
5.88981E+06	9.26451E-03	0.1 %

Increment of load	**FORC_NODA point** D	**Reference**	**Précision**
1: $Mz=3.08670\,D{+}06\,Nm$	DY	0.0109349	3,0 %
1: $Mz=3.08670\mathrm{D}+06\mathrm{Nm}$	DRZ	3.086700E6	0.1 %
8: $Mz=5.88981\,D{+}06\,Nm$	DY	0.0220836	3,0 %
8: $Mz=5.88981\mathrm{D}+06\mathrm{Nm}$	DRZ	5.889810E6	0.1 %

Increment of load	**FORC_NODA point** A	**Reference**	**Précision**
1: $Mz=3.08670\mathrm{D}+06\mathrm{Nm}$	DRZ	-3.086700E6	0.1 %
8: $Mz=5.88981\mathrm{D}+06\mathrm{Nm}$	DRZ	-5.889810E6	0.1 %

Increment of load	**DEPL point** D	
8: $Mz=5.88981\mathrm{D}+06\mathrm{Nm}$	DY	NON_REGRESSION

Tests of nonregression for the options of CALC_CHAMP or POST_CHAMP :

Option	Component	Mesh	Not	Under -point	Sequence number	*Reference*	*Precision*
SIEQ_ELGA	VMIS	M1	2	61	1	4.675554583E+07	1%
SIEQ_ELGA	VMIS	M1	3	55	3	5.608141169E+07	1%
SIEQ_ELGA	VMIS_SG	M1	2	98	8	-1.550065323E8	1%
SIEQ_ELGA	VMIS_SG	M1	3	42	8	-7.143706272E6	1%
EPEQ_ELGA	INVA_2	M1	1	77	4	2.590281477E-04	1%
EPEQ_ELGA	INVA_2	M1	1	8	5	0.00017692929323	1%
EPEQ_ELGA	INVA_2SG	M1	1	61	8	-3.527683756E-4	1%
EPEQ_ELGA	INVA_2SG	M1	3	9	8	-8.940141939E-05	1%

Tests of the special quantities for the earthquake at the point D :

Increment of load		Précision
$Mz=3.08670\,D{+}06\,Nm$	EN	NON_REGRESSION
$Mz=3.48715\,D{+}06\,Nm$	ET	NON_REGRESSION
$Mz=4.288041\,D{+}06\,Nm$	EFY	NON_REGRESSION
$Mz=5.489370\,D{+}06\,Nm$	EFZ	NON_REGRESSION
$Mz=5.889810\,D{+}06\,Nm$	$ESTAR$	NON_REGRESSION

Tests of the special quantities for the earthquake at the point C :

Increment of load		Précision
$Mz=3.08670\,D{+}06\,Nm$	EN	NON_REGRESSION
$Mz=3.48715\,D{+}06\,Nm$	ET	NON_REGRESSION
$Mz=4.288041\,D{+}06\,Nm$	EFY_2	NON_REGRESSION
$Mz=5.489370\,D{+}06\,Nm$	EFZ_2	NON_REGRESSION
$Mz=5.889810\,D{+}06\,Nm$	$ESTAR_2$	NON_REGRESSION

Validation of POST_CHAMP/MIN_MAX_SP. For the following tests, all the precise details are to 0.0002%;

Option	Component	Component	Mesh	Not	Sequence number	AUTRE_ASTER
SIEQ_ELGA	VMIS/MAXI	VALLEYE	M3	1	1	1.0700867361796001E8
SIEQ_ELGA	VMIS/MINI	VALLEYE	M3	1	1	8.3875661619263999E6
SIEQ_ELGA	VMIS/MAXI_ABS	VALLEYE	M3	2	1	8.3938035236909002E7
SIEQ_ELGA	VMIS/MINI_ABS	VALLEYE	M3	2	1	70047.6053304
SIEQ_ELGA	VMIS/MAXI	NUCOU	M3	1	1	1.0
SIEQ_ELGA	VMIS/MAXI	NUSECT	M3	1	1	1.0
SIEQ_ELGA	VMIS/MAXI	POSIC	M3	1	1	-1.0
SIEQ_ELGA	VMIS/MAXI	POSIS	M3	1	1	-1.0
SIEQ_ELGA	VMIS/MAXI	VALLEYE	M1	1	1	8.8409900E7
SIEQ_ELGA	VMIS/MINI	VALLEYE	M1	1	1	5.883180E6
SIEQ_ELGA	VMIS/MAXI	NUCOU	M2	2	1	1.0
SIEQ_ELGA	VMIS/MINI	NUCOU	M3	3	1	1.0
SIEQ_ELGA	VMIS/MAXI	NUSECT	M4	1	1	12.0
SIEQ_ELGA	VMIS/MINI	NUSECT	M5	2	1	16.0
SIEQ_ELGA	VMIS/MAXI	POSIC	M6	3	1	-1.0
SIEQ_ELGA	VMIS/MINI	POSIC	M7	1	1	0
SIEQ_ELGA	VMIS/MAXI	POSIS	M8	2	1	1.0

SIEQ_ELGA	VMIS/MINI	POSIS	M9	3	1	1.0
SIEQ_ELGA	VMIS/MAXI	VALLEYE	M1	2	4	1.27695000E8
SIEQ_ELGA	VMIS/MINI	VALLEYE	M5	3	5	2.2075500E7

Validation of CREA_CHAMP/ELGA_SPMX_R. For the following tests (NON_REGRESSION), all the precise details are to 0.0001%;

SIEQ_ELGA	VMIS/MAXI	VALLEYE	M1	1	MAXIMUM
SIEQ_ELGA	VMIS/MINI	INST	M5	3	MAXIMUM
VARI_ELNO	V5	VALLEYE	M5	N13	MAXIMUM

Validation of POST_CHAMP/VARI_ELNO. For the following tests (AUTRE_ASTER), all the precise details are to 0.0000001%;

VARI_ELNO	V5	NUCOU	M5	N13	MAXIMUM	1.0
VARI_ELNO	V5	NUSECT	M5	N13	MAXIMUM	12.0
VARI_ELNO	V5	POSIC	M5	N13	MAXIMUM	-1.0
VARI_ELNO	V5	POSIS	M5	N13	MAXIMUM	1.0

The fact of using the Mfront behavior does not change the precision of the solutions tested compared to the 3D.

5 Summary of the results

The reference solution analytical, but digital (not being obtained by a modeling 3D), variations noted (of 1% with 3%) can be regarded as reasonable. To obtain a better correspondence of the solutions 3D and PIPE, it would be advisable to model the right parts over a bigger length, and to adopt a finer grid for each modeling. This was not done within the framework of this test, to keep reasonable execution times.