SSNV115 - Corrugated iron in Summarized nonlinear

behavior:

This problem validates the elastoplastic constitutive law with criterion of Von Mises with isotropic linear hardening for the modelizations of plates [R3.07.03] and voluminal shells [R3.07.04] where the effects of membrane and bending are also important.

The geometry of the model respects 3 stresses:

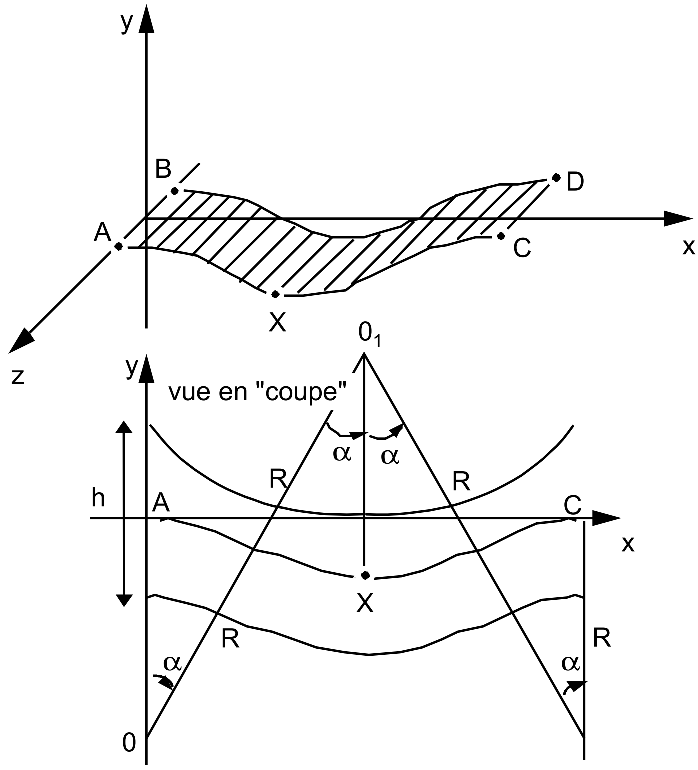
- the thickness is low to respect the assumption of the thin shells,
- the problem must be in plane strain according to Oz ,
- the curvature according to Oy is selected so that "bending" and the "membrane" are both significant.

There is no analytical solution. The modelization A (`2D D_PLAN`) is used as reference. The test and the does not have physical meaning values of displacements obtained are very important compared to dimensions of initial structure. This test is thus rather a test of NON-regression and comparison inter - modelizations.

The results (in displacement) differ from 2 to 3% between the modelizations plates and the reference 2D. This variation is reduced to 0.5% between the modelizations voluminal shells and the reference 2D.

1 Problem of reference

1.1 Geometry



Characteristics of the shell:

- thickness $h=0.05\,mm$,
- radius of curvature $R=1\,mm$,
- width $L=AB=CD=0.1\,mm$,
- position of the first center of curvature: $0=(0,-R)$ et $\|OA\|=R=0.1$,
- the angle α selected so that the surface **upper** of the shell than the point X is with $(y=0)$, i.e. is aligned with A and C ,

$$\cos\ \alpha\ =\ 1-\frac{1}{4}\frac{h}{R}$$

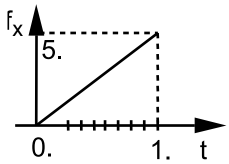
- position of the second center of curvature: $0_1\left(2R\cos\alpha, R-\frac{h}{2}\right)$ et $\|0,x\|=R$.

1.2 Material properties

$E=2\ 000\,MPa$
$\nu=0.3$
One uses an elastoplastic constitutive law with criterion of Von Mises with linear isotropic hardening: $\sigma_y=100\,MPa$ $E_T:200\,MPa$.

1.3 Boundary conditions and loadings

- on AB : fixed support: $DX=DY=DZ=DRX=DRY=DRZ=0$,
- on all the shell: plane strain according to Oz is $DZ=DRX=DRY=0$,
- on CD : linear force (by unit of length Oz) according to Ox given by: $f_x=50\,N/mm$ It is equivalent to a pressure of $p_X=f_x/h=100\,MPa$ being exerted on the side CD ,
- the loading is applied gradually to structure. The way of loading is cut out in 10 equal increments.



2 Reference solution

2.1 Méthode de calcul used for the reference solution

The modelization A (`2D D_PLAN`) is used as reference for the modelizations of shell.

2.2 Results of reference

Displacements according to Ox and Oy of the point X in mm .

2.3 Uncertainty on the solution

the experiment shows that if one doubles the number of elements in the two directions, result varies from less than 2%.

The selected convergence criteria must also make it possible 2D to reach the accuracy estimated for this computation: (2 or 3%).

3 Bibliography

1) F. VOLDOIRE, C. SEVIN: Axisymmetric thermo-elastic shells and 1D. Documentation of reference of *the Code_Aster* [R3.07.02].

2) P. MASSIN: Shell elements DKT, DST, DKQ, DSQ and Q4 γ. Documentation of reference of *the Code_Aster* [R3.07.03].

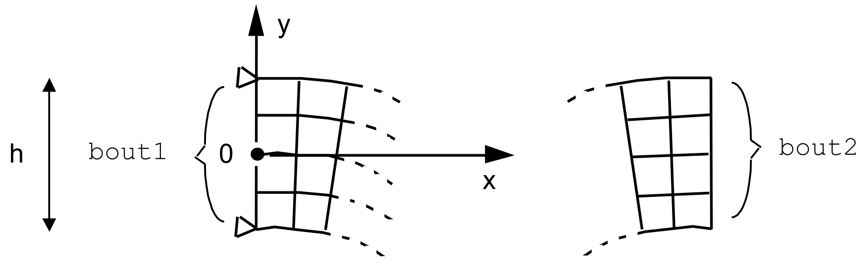
3) P. MASSIN, A. LAULUSA: Shell elements three-dimensional. Documentation of reference of *the Code_Aster* [R3.07.04].

4 Modelization A

4.1 Characteristic of the modelization

Discretization : 20 X 4 elements QUAD8 with modelization `D_PLAN`.

Boundary conditions:



0 : DX = DY = 0.
`bout1` : DX = 0.

Name of the nodes : not X = `group_no X = N148`

Loading : linear force (by unit of length Oz) FX distributed on `the group_ma bout2` $FX=5./h=100.$ This loading is equivalent to a pressure of $100\,MPa$.

4.2 Characteristics of the mesh

Many nodes:	289
Number of meshes and type:	80 QUAD8

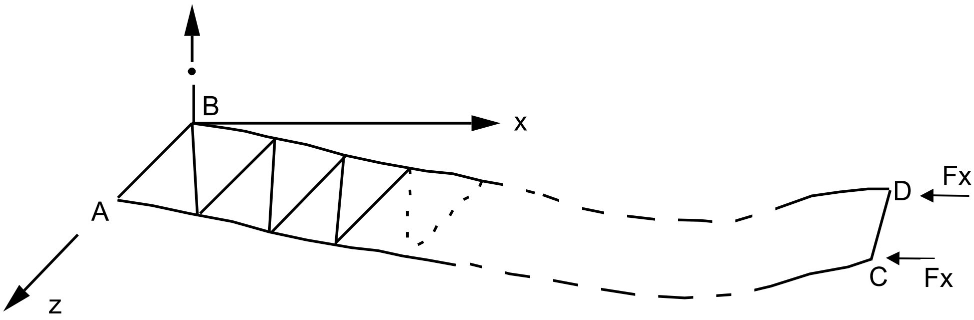
4.3 Values tested

At the sequence number 10

Identification	***Aster*** **(** mm **)**
$DX(X)$ to $t=1.$	0.02743
$DY(X)$ with $t=1.$	– 0.2804

5 Modelization B

5.1 Characteristic of the modelization



One seeks a motion independent of z ; only one "line" of triangular elements is thus enough.

Cutting : 20 quadrangles => 40 triangles DKT. Modelization `DKT`.

The thickness of the elements is divided into 17 layers for nonlinear computation [R3.07.03]. Each layer comprises 3 points of integration in higher skin of layer, in the middle of each layer and in lower skin of layer. The model studied here thus understands 15 points of integration in the thickness of the plate.

Boundary conditions:

```
AB (GROUP_NO: bout1): DX = DY = DZ = DRX = DRY = DRZ = 0
TOUT: "OUI': DZ = DRX = DRY = 0
```

Loading : nodal forces in C and D $FX=pXLh/2=0.25\,N$.

5.2 Characteristics of the mesh

Many nodes: 42
Number of meshes and type: 40 TRIA3

5.3 Values tested

At the sequence number 10 are $t=1$.

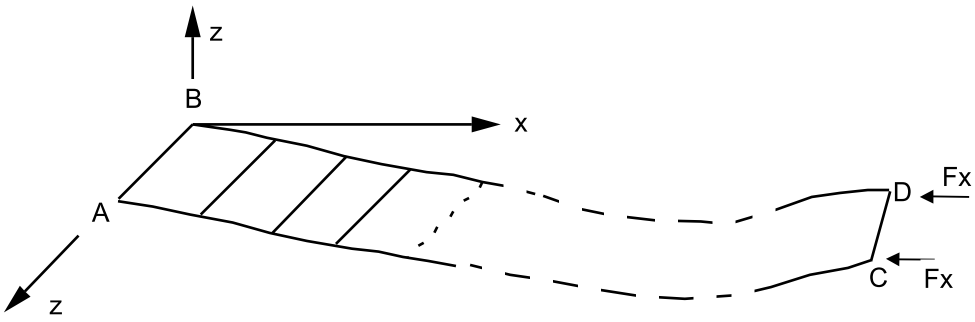
Identification	Reference
$DX(X)$	0.02743
$DY(X)$	– 0.2804
$FX(A)$	– 0.25

Note::

If one further increases the number of layers for integration in the thickness, the relative error on $DX(X)$ *master key below 2%. For 19 layers one finds an error of 1.29% thus. That on* $DY(X)$ *rest unchanged.*

6 Modelization C

6.1 Characteristic of the modelization



One seeks a motion independent of z ; only one “line” of quadrangular elements is thus enough.

Cutting : 40 quadrangles DKQ. Modelization `DKT`.

The thickness of the elements is divided into 7 layers for nonlinear computation [R3.07.03], in order to have a very high degree of accuracy on the stress state in the thickness of the plate. Each layer comprises 3 points of integration in higher skin of layer, in the middle of each layer and in lower skin of layer. The model studied here thus understands 15 points of integration in the thickness of the plate.

Boundary conditions:

```
AB (GROUP_NO: bout1): DX = DY = DZ = DRX = DRY = DRZ = 0
TOUT: "OUI': DZ = DRX = DRY = 0
```

Loading : nodal forces in C and D $FX = pXLh/2 = 0.25\,N$.

6.2 Characteristics of the mesh

Many nodes:	82
Number of meshes and type:	40 QUA4

6.3 Values tested

At the sequence number 10 are $t=1$.

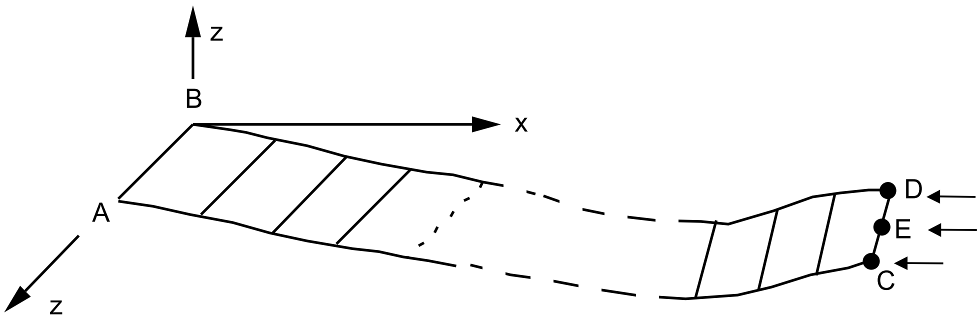
Identification	Reference
$DX(X)$	0.02743
$DY(X)$	– 0.2804
$FX(A)$	– 0.25

Note::

If one further increases the number of layers for integration in the thickness the relative error on $DX(X)$ master key below 1%. That on $DY(X)$ rest unchanged.

7 Modelization D

7.1 Characteristic of the modelization



One seeks a motion independent of Z; only one "line" of quadrangular elements is thus enough.

Cutting : 8 quadrangles MEC3QU9H. Modelization `COQUE_3D`.

The thickness of the elements is divided into 3 layers for nonlinear computation [R3.07.04]. Each layer comprises 3 points of integration in higher skin of layer, in the middle of each layer and in lower skin of layer. The model studied here thus understands 7 points of integration in the thickness of the plate.

Boundary conditions:

```
AB (GROUP_NO: AB): DX = DY = DZ = DRX = DRY = DRZ = 0
TOUT: "OUI': DZ = DRX = DRY = 0
```

Loading : two types of loading are applied:

- nodal forces in C and D E (medium node on the side CD) FX (C) = $FX(D)=pxLh/6=0.08333\text{N}$
  $FX(E)=2\text{pxLh}/3=0.33\text{N}.$
- distributed force on the side CD $FX=5\text{N}/mm$.

7.2 Characteristics of the mesh

Many nodes:	43 external + 8 interns
Number of meshes and types:	8 QUA9 + 1 SEG3

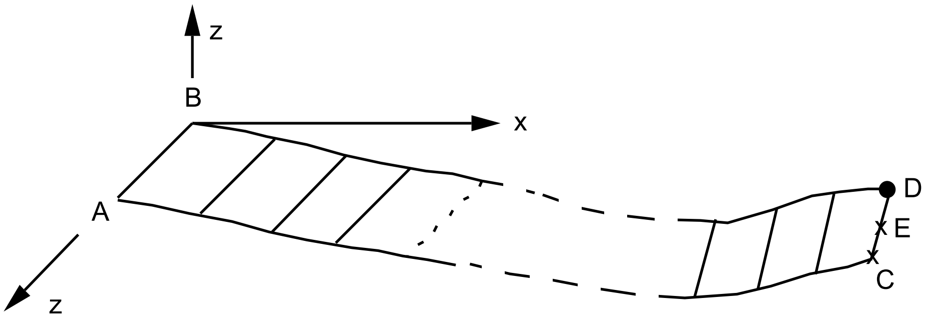
7.3 Values tested

At the sequence number 10 is $t=1$. The results are identical with `FORCE_NODALE` or `FORCE_ARETE`.

Identification	Reference
$DX(X)$	0.02743
$DY(X)$	– 0.2804

8 Modelization E

8.1 Characteristic of the modelization



One seeks a motion independent of Z; only one "line" of quadrangular elements is thus enough.

Cutting : 12 triangles MEC3TR7H. Modelization `COQUE_3D`.

The thickness of the elements is divided into 3 layers for nonlinear computation [R3.07.04]. Each layer comprises 3 points of integration in higher skin of layer, in the middle of each layer and in lower skin of layer. The model studied here thus understands 7 points of integration in the thickness of the plate.

Boundary conditions:

```
AB (GROUP_NO: AB): DX = DY = DZ = DRX = DRY = DRZ = 0
TOUT: "OUI': DZ = DRX = DRY = 0
```

Loading : two types of loading are applied:

- nodal forces in C and D E (medium node on the side CD) $FX(D)=pxLh/6=0.08333N$
  FX (C) =
  $FX(E)=2\text{pxLh}/3=0.33\text{N}.$
- distributed force on the side CD $FX=5\text{N}/mm.$

8.2 Characteristics of the mesh

Many nodes:	75 external + 24 interns
Number of meshes and types:	24 TRIA7 + 1 SEG3

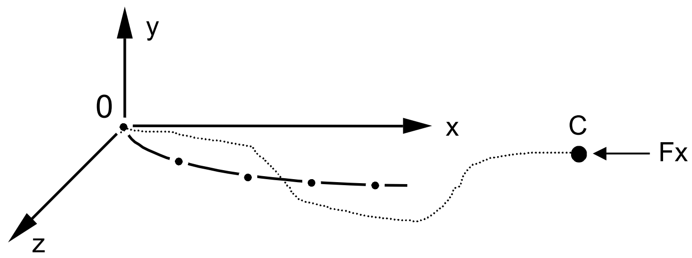
8.3 Values tested

At the sequence number 10 is $t=1$. The results are identical with `FORCE_NODALE` or `FORCE_ARETE`.

Identification	Reference
$DX(X)$	0.02743
$DY(X)$	– 0.2804

9 Modelization F

9.1 Characteristic of the modelization



Cutting : 20 segments => 20 segments SEG3. Modelization `COQUE_D_PLAN`.

The thickness of the elements is divided into 7 layers for nonlinear computation [R3.07.02]. Each layer comprises 3 points of integration in higher skin of layer, in the middle of each layer and in lower skin of layer. The model studied here thus understands 15 points of integration in the thickness of the plate.

Boundary conditions:

(THE NODE IS OUTSIDE THE FIELD OF DEFINITION WITH A RIGHT PROFILE OF THE EXCLU TYPE NODE: 0): DX = DY = DZ = DRX = DRY = DRZ = 0

Loading :

- nodal force in C : $FX(C)=pXh=5\mathrm{N}/mm$.

9.2 Characteristics of the mesh

Many nodes: 41
Number of meshes and type: 20 SEG3

9.3 Values tested

At the sequence number 10 are $t=1$. The values given by means of as tangent matrix that calculated numerically are:

Identification	Reference	**Aster** (mm)	% difference
$DX(X)$	0.02743	0.02753	0.381
$DY(X)$	– 0.2804	– 0.2848	1.556

At the sequence number 10 is $t=1$. The values given by means of as tangent matrix the elastic matrix are:

Identification	Reference	**Aster** (mm)	% difference
$DX(X)$	0.02743	0.02753	0.383
$DY(X)$	– 0.2804	– 0.2848	1.558

Note::

To put 3 layers for integration in the thickness leads to an error of 2.4% on the estimate of $DX(X)$.

10 Summary of the results

One 2D notices the good adequacy of the reference solution Aster plane strain with the results got by the modelizations in voluminal shells. The variation on displacements at the point of maximum deflection on the initial geometry is indeed lower than 1%. The variation with the modelization in linear shell is of about a 1.5% on the estimate of the maximum deflection of sheet. This variation becomes more important for the modelizations in shell elements which do not take into account the curvature of corrugated iron. The relative error on the estimate of the maximum deflection does not seem to want to go down below 3%, and this same by increasing the number of layers to improve integration of plasticity in the thickness of the element. It is noticed for this reason that an increase amongst layers in the thickness makes it possible to improve the estimate of displacement DX at the point where the deflection is maximum without to improve the estimate of the latter, and this, for all the studied models. The difference in quality of results between the various models undoubtedly comes from the taking into account of the curvature of corrugated iron.