SSNV115 - Corrugated iron in behavior nonlinear

Summary:

This problem validates the elastoplastic law of behavior with criterion of Von Misès with isotropic linear work hardening for modelings of plates [R3.07.03] and voluminal hulls [R3.07.04] where the effects of membrane and inflection are also important.

The geometry of the model respects 3 constraints:

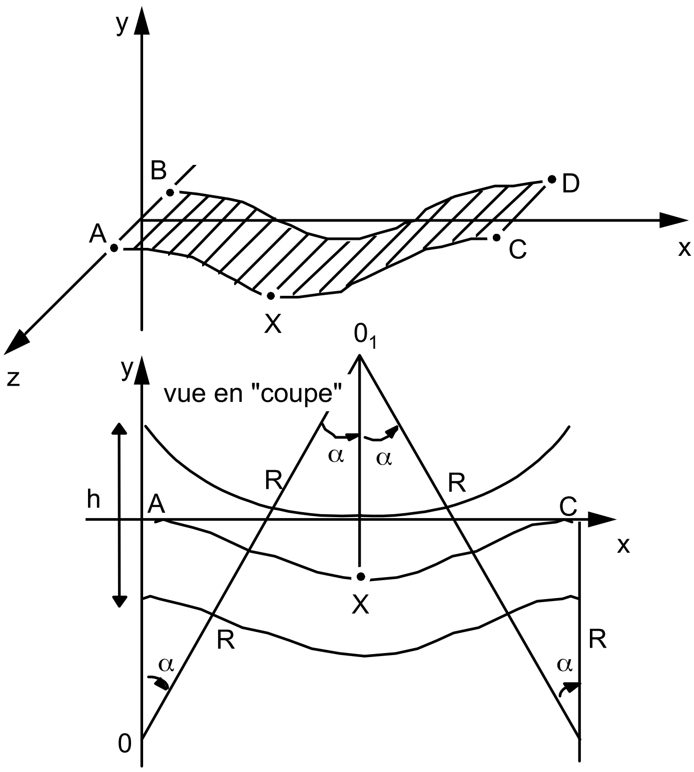
- the thickness is low to respect the assumption of the thin hulls,
- the problem must be in plane deformation according to Oz,
- curve according to Oy is selected so that the "inflection" and the "membrane" are both significant.

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

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

1 Problem of reference

1.1 Geometry



Characteristics of the hull:

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

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

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

1.2 Material properties

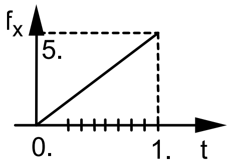
$E=2\ 000\,MPa$

$\nu=0.3$

One uses an elastoplastic law of behavior with criterion of Von Misès with linear isotropic work hardening: $\sigma_y=100\,MPa$ $E_T:200\,MPa$.

1.3 Boundary conditions and loadings

- on AB : embedding: $DX=DY=DZ=DRX=DRY=DRZ=0$,
- on all the hull: deformation planes according to Oz that is to say $DZ=DRX=DRY=0$,
- on CD : linear effort (per 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 the structure. The way of loading is cut out in 10 equal increments.



2 Reference solution

2.1 Method of calculating used for the reference solution

Modeling A (`2D D_PLAN`) is used as reference for modelings of hull.

2.2 Results of reference

Displacements according to Ox and Oy 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, the result varies from less than 2%.

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

3 Bibliography

1) F. VOLDOIRE, C. SEVIN: Axisymmetric thermoelastic hulls and 1D. Reference material of *Code_Aster* [R3.07.02].

2) P. MASSIN: Elements of plate DKT, DST, DKQ, DSQ and Q4 γ. Reference material of *Code_Aster* [R3.07.03].

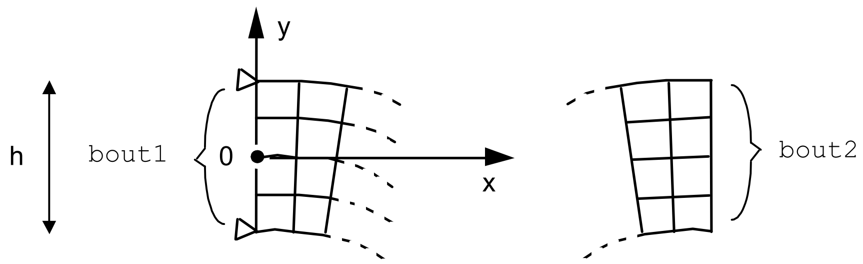
3) P. MASSIN, A. LAULUSA: Elements of three-dimensional hull. Reference material of *Code_Aster* [R3.07.04].

4 Modeling A

4.1 Characteristics of modeling

Discretization : 20 X 4 elements QUAD8 with modeling D_PLAN.

Boundary conditions:



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

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

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

4.2 Characteristics of the grid

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

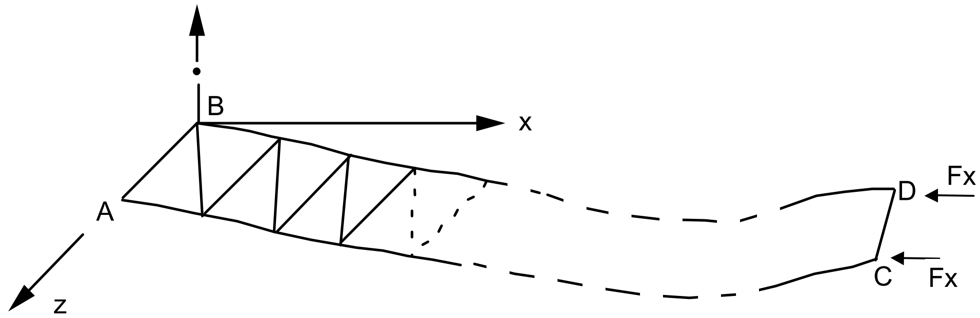
4.3 Values tested

With the sequence number 10

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

5 Modeling B

5.1 Characteristics of modeling



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

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

The thickness of the elements is divided into 17 layers for nonlinear calculation [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 here studied thus understands 15 points of integration in the thickness of the plate.

Boundary conditions:

```
AB (GROUP_NO: bout1): DX = DY = DZ = DRX = DRY MARTINI = DRZ = 0
ALL: 'YES': DZ = DRX = DRY MARTINI = 0
```

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

5.2 Characteristics of the grid

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

5.3 Values tested

With the sequence number 10 is $t=1$.

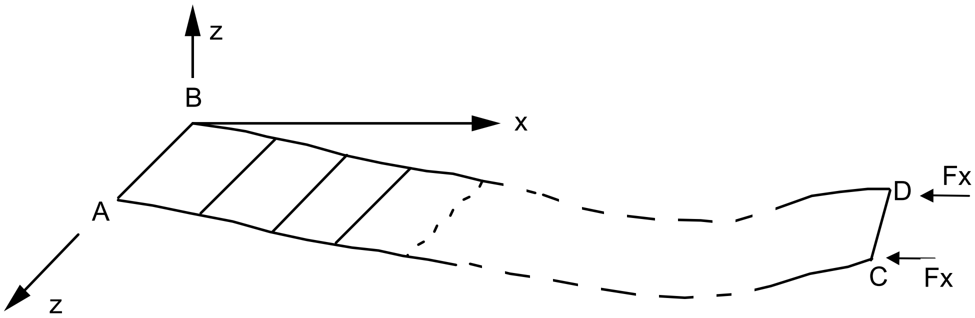
Identification	Reference
$DX(X)$	0.02743
$DY(X)$	– 0.2804
$FX(A)$	– 0.25

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 $DY(X)$ remain unchanged.

6 Modeling C

6.1 Characteristics of modeling



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

Cutting : 40 quadrangles DKQ. Modeling `DKT`.

The thickness of the elements is divided into 7 layers for nonlinear calculation [R3.07.03], in order to have a very high degree of accuracy on the state of stresses 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 MARTINI = DRZ = 0
ALL: 'YES': DZ = DRX = DRY MARTINI = 0
```

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

6.2 Characteristics of the grid

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

6.3 Values tested

With the sequence number 10 is, $t=1$.

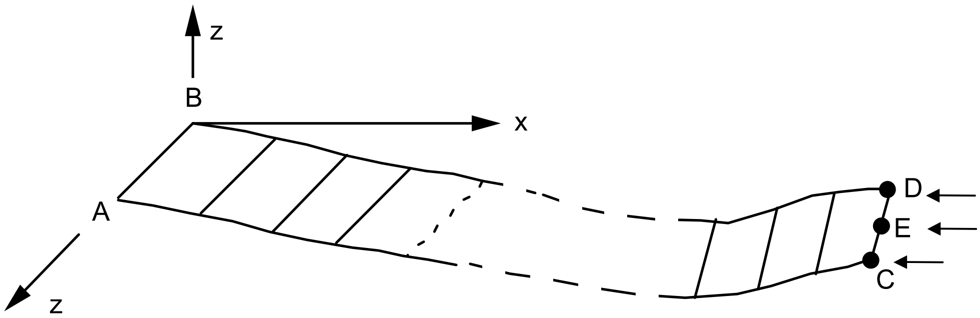
Identification	Reference
$DX(X)$	0.02743
$DY(X)$	– 0.2804
$FX(A)$	– 0.25

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* $DY(X)$ *remain unchanged.*

7 Modeling D

7.1 Characteristics of modeling



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

Cutting : 8 quadrangles MEC3QU9H. Modeling `COQUE_3D`.

The thickness of the elements is divided into 3 layers for nonlinear calculation [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 here studied thus understands 7 points of integration in the thickness of the plate.

Boundary conditions:

```
AB (GROUP_NO: AB): DX = DY = DZ = DRX = DRY MARTINI = DRZ = 0
ALL: 'YES': DZ = DRX = DRY MARTINI = 0
```

Loading : two types of loading are applied:

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

7.2 Characteristics of the grid

Many nodes:	43 external + 8 interns
Many meshs and types:	8 QUA9 + 1 SEG3

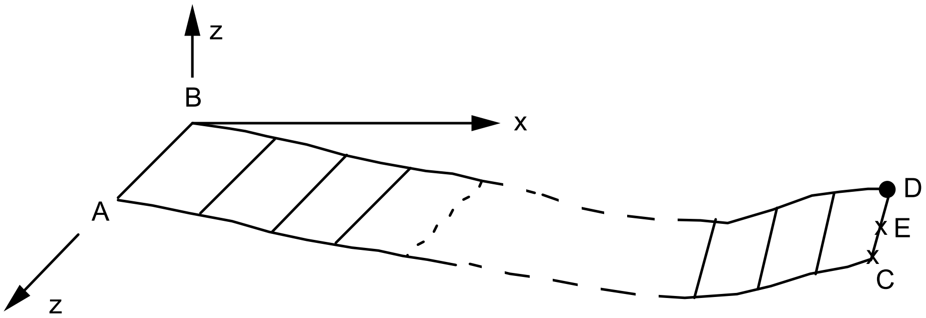
7.3 Values tested

With 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 Modeling E

8.1 Characteristics of modeling



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

Cutting : 12 triangles MEC3TR7H. Modeling `COQUE_3D`.

The thickness of the elements is divided into 3 layers for nonlinear calculation [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 here studied thus understands 7 points of integration in the thickness of the plate.

Boundary conditions:

```
AB (GROUP_NO: AB): DX = DY = DZ = DRX = DRY MARTINI = DRZ = 0
ALL: 'YES': DZ = DRX = DRY MARTINI = 0
```

Loading : two types of loading are applied:

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

8.2 Characteristics of the grid

Many nodes:	75 external + 24 interns
Many meshs and types:	24 TRIA7 + 1 SEG3

8.3 Values tested

With 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 Summary of the results

One notices the good adequacy of the reference solution *Aster* 2D deformation planes with the results got by modelings in voluminal hulls. The variation on displacements at the point of maximum arrow on the initial geometry is indeed lower than 1%. The variation with modeling in linear hull is of about a 1.5% on the estimate of the maximum arrow of sheet. This variation becomes more important for modelings in elements of plates which do not take into account the curve of corrugated iron. The relative error on the estimate of the maximum arrow 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 arrow is maximum without to improve the estimate of the latter, and this, for the whole of the studied models. The difference in quality of results between the various models undoubtedly comes from the taking into account of the curve of corrugated iron.