



**UNIMORE**  
UNIVERSITÀ DEGLI STUDI DI  
MODENA E REGGIO EMILIA



Dipartimento di Ingegneria  
“Enzo Ferrari”

# Progettazione Assistita di Organi di Macchine

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# Agenda

## MSC Marc Mentat: Select entities

- Method & Mode;
- Store;
- Identify set.

## Thin-walled profile in torsion

- Opened vs closed cross-section;
- Mesh convergence.

## References

# Agenda

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## References

# MENU: SELECT

MESH GENERATION

NODES	ADD	REM	EDIT	SHOW
ELEMS	ADD	REM	EDIT	SHOW
PTS	ADD	REM	EDIT	SHOW
CRVS	ADD	REM	EDIT	SHOW
SRFS	ADD	REM	EDIT	SHOW
SOLIDS	ADD	REM		SHOW
BETWEEN NODE		BETWEEN POINT		
ELEMENT CLASS	▼ QUAD (4)			
CURVE TYPE	▼ LINE			
SURFACE TYPE	▼ QUAD			
SOLID TYPE	▼ BLOCK			
COORDINATE SYSTEM				
SET	▼ RECTANGULAR		GRID	
CLEAR MESH	CLEAR GEOM			
ATTACH	AUTOMESH			
CHANGE CLASS	CHECK			
CONVERT	DUPLICATE			
ELEMENT TYPES	EXPAND			
INTERSECT	MOVE			
RELAX	RENUMBER			
REVOLVE	SOLIDS			
STRETCH	SUBDIVIDE			
SWEEP	SYMMETRY			
ALL:	SELEC	VISIB	OUTL	TOP
EXIST:	UNSEL	INVIS	SURF	BOT
SELECT	SET	END LIST (#)		
RETURN	MAIN			

1

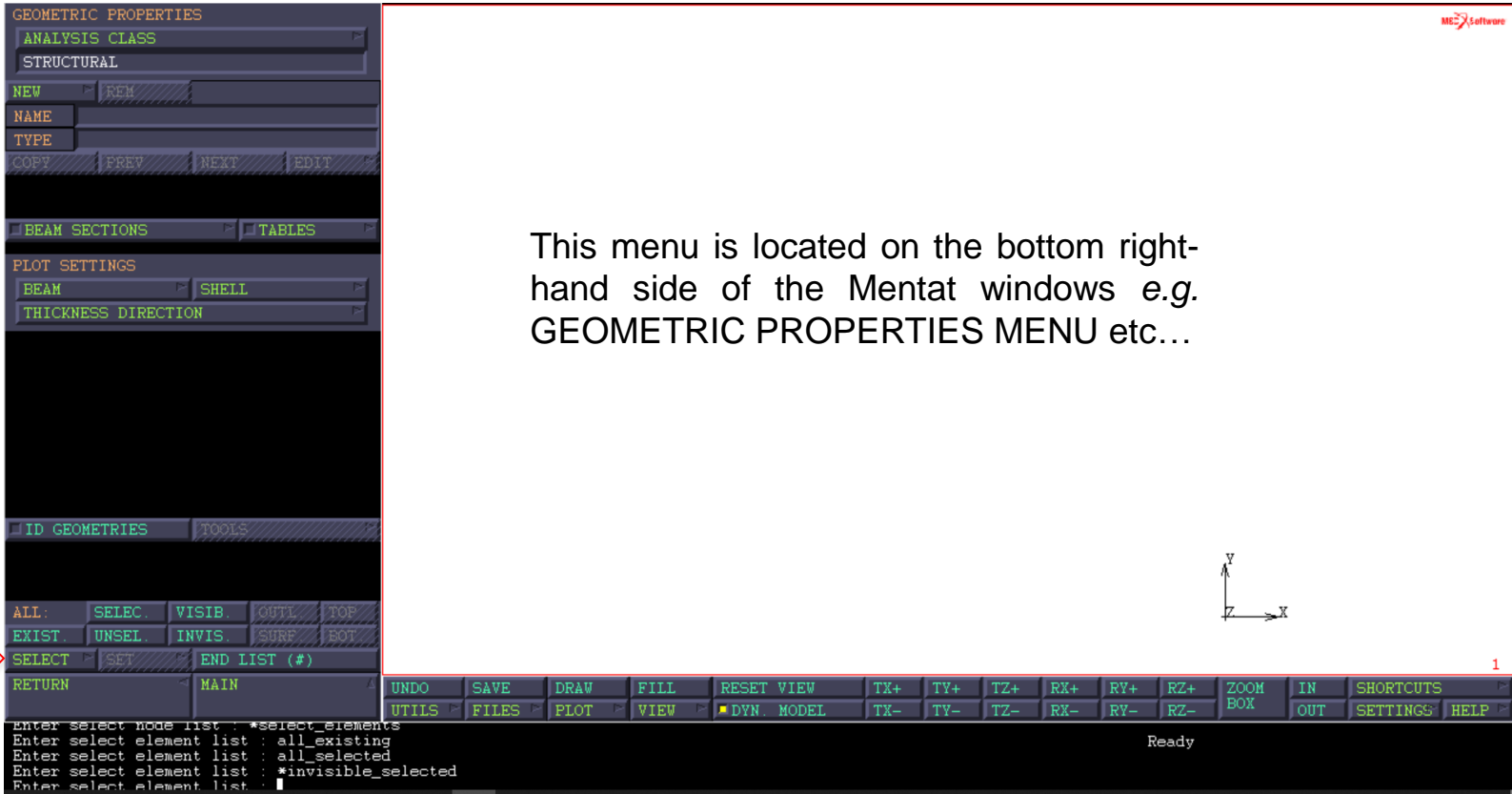
UNDO SAVE DRAW FILL RESET VIEW TX+ TY+ TZ+ RX+ RV+ RZ+ ZOOM IN SHORTCUTS  
UTILS FILES PLOT VIEW ▼ DYN. MODEL TX- TY- TZ- RX- RV- RZ- BOX OUT SETTINGS HELP

Ready

Enter select node list : \*select\_elements  
Enter select element list : all\_existing  
Enter select element list : all\_selected  
Enter select element list : \*invisible\_selected  
Enter select element list :

This menu contains commands for selecting model entities and for creating sets of entities. This menu is located on the bottom right-hand side of the Mentat windows e.g. MESH GENERATION.

# MENU: SELECT



GEOMETRIC PROPERTIES

ANALYSIS CLASS  
STRUCTURAL

NEW REM

NAME

TYPE

COPY PREV NEXT EDIT

BEAM SECTIONS TABLES

PLOT SETTINGS  
BEAM SHELL  
THICKNESS DIRECTION

ID GEOMETRIES TOOLS

ALL: SELEC VISIB OUTL TOP  
EXIST UNSEL INVIS SURF BOT

SELECT SET END LIST (#)

RETURN MAIN

UNDO SAVE DRAW FILL RESET VIEW TX+ TY+ TZ+ RX+ RY+ RZ+ ZOOM IN SHORTCUTS  
UTILS FILES PLOT VIEW DYN. MODEL TX- TY- TZ- RX- RY- RZ- BOX OUT SETTINGS HELP

Enter select node list : \*select\_elements  
Enter select element list : all\_existing  
Enter select element list : all\_selected  
Enter select element list : \*invisible\_selected  
Enter select element list : █

Ready

1

Mentat Software

Y  
Z X

This menu is located on the bottom right-hand side of the Mentat windows e.g. GEOMETRIC PROPERTIES MENU etc...

# Select entities

e.g. nodes, elements, points, curves, ...

This command adds *nodes (or elements, or edges, or faces, ...)* to the list of selected nodes (*or elements, or edges, or faces, ...*).

Once nodes (*or elements, or edges, or faces, ...*) are selected, they might be **stored** in a set with a prescribed named.

The selection can be performed adopting a peculiar METHOD and/or a SELECT MODE. These aspects will be presented in the following.

# Select entities: METHOD

e.g. nodes, elements, points, curves, ...

**SINGLE:** this method allows the user to select entities singly by specifying their *IDs* or by manual selection (mouse). This method is the *default method*.

**PATH:** this method allows the user to select connected nodes or points along a path from the first entity specified to the last. You may specify only the beginning and end of the path, or choose entities at various location along the path.

**BOX:** this method allows the user to select items within a specified region in space therefore a volume assessed by coordinates. All items that fall within the specified box (global coordinate system) become selected.



# Select entities: MODE

e.g. nodes, elements, points, curves, ...



**AND:** adopting this mode, additionally selected entities are added with those already in the selected list, thus adding them to the list. This mode is the *default mode*.

**EXCEPT:** by this mode, additionally selected entities are removed from the list of selected entities.

**INVERT:** in this mode, additionally selected entities are added to the list of selected entities if they do NOT belong to it and are removed if they do already belong to it.

**INTERSECT:** in this mode, additionally selected entities are intersected with the current list of selected entities to form the new list.

→ I suggest you to do some exercises!!!!



# Select entities: STORE

e.g. nodes

Once nodes (or elements, or edges, or faces, ...) are selected, they might be **stored** in a set with a prescribed named.

STORE  
Type the set named  
e.g. *crucial\_nodes*  
Press ENTER  
OK  
ALL: SELECT  
NODES: CLR  
 IDENTIFY SETS

This command turns on the identification of set identifiers of all sets in the model by colours.

Marc Mentat 2013.1.0 (64bit) (OpenGL): model3.mud

SELECT

NODES	4	CLR	STORE
ELEMENTS	0	CLR	STORE
... EDGES	0	CLR	STORE
... FACES	0	CLR	STORE
POINTS	0	CLR	STORE
CURVES	0	CLR	STORE
SURFACES	0	CLR	STORE
SOLIDS	0	CLR	STORE
VERTCS	0	CLR	STORE
EDGES	0	CLR	STORE
FACES	0	CLR	STORE

SELECT SET: SELECT BY

SELECT CONTACT BODY ENTITIES

FILTER: NONE

METHOD: SINGLE

SELECT MODE: AND

CLEAR SELECT: RESET

MAKE VISIBLE: MAKE INVISIBLE

EXCLUDE INVISIBLE BODIES

STORE NODE PATH: STORE ORDERED

SETS: RENAME REMOVE MERGE

DEL ENTRIES: VISIBILITY

IDENTIFY SETS: IDENTIFY

ALL: SELEC. VISIB OUTL TOP

EXIST. UNSEL. INVIS. SURF BOT

SELECT SET END LIST (#)

RETURN MAIN

UNDO SAVE DRAW FILL RESET VIEW TX+ TY+ TZ+ RX+ RY+ RZ+ ZOOM IN SHORTCUTS

UTILS FILES PLOT VIEW DYN. MODEL TX- TY- TZ- RX- RY- RZ- ZOOM BOX OUT SETTINGS HELP

Ready

18:51

# Select entities: IDENTIFY SETS

e.g. nodes

## ☒ IDENTIFY SETS

This command turns on the identification of set identifiers of all sets in the model by colours

e.g. the nodes of this quadrilateral elements are store in a set called *crucial\_nodes* identified by the rose colour.

The screenshot shows a software interface with a 'SELECT' menu on the left. A red arrow points to the 'IDENTIFY SETS' option. The main window displays a quadrilateral element with a pink 'X' and a legend for 'crucial\_nodes' (pink) and 'none' (grey). A coordinate system (X, Y, Z) is shown in the bottom right. The bottom status bar shows 'Ready' and a small red '1'.

# Agenda

MSC Marc Mentat: Select entities

- Method & Mode;
- Store;
- Identify set.

**Thin-walled profile in torsion**

- Opened vs closed cross-section;
- Mesh convergence.

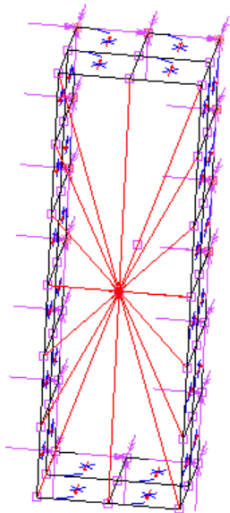
References

# Thin-walled profile in torsion

## Opened vs closed cross-section

### GOAL:

Open the reference model named `torsione_rev01_nolabile.mud` this profile is characterized by a lateral crack (open-cross section). It is loaded on the free extremity by an imposed rotation.



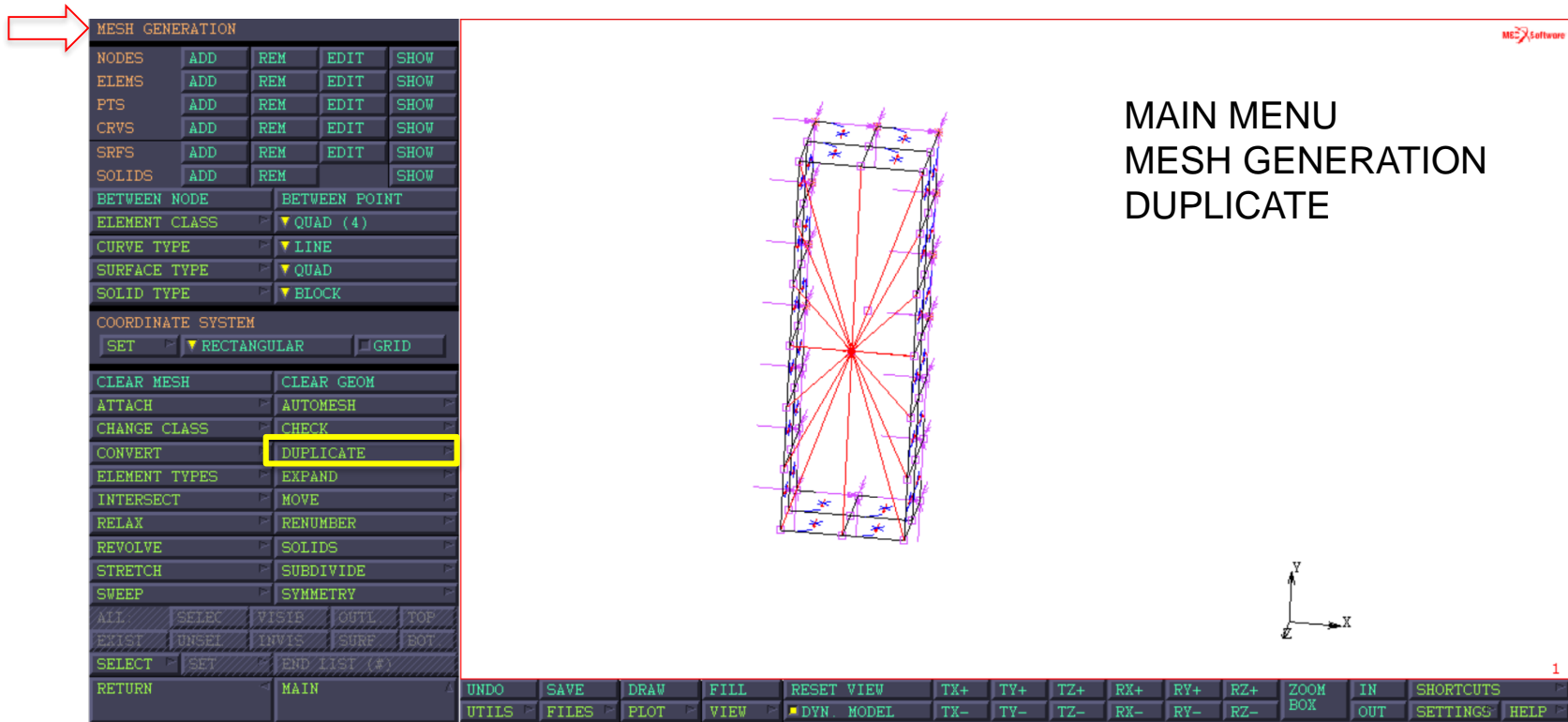
Starting from this model, we will compare the response of the open section profile with the homologous closed profile calculating their torsional stiffness.

`torsione_rev01_nolabile_open_vs_close.mud`



# MESH GENERATION

## Duplicate



MAIN MENU  
MESH GENERATION  
DUPLICATE

1

# Duplicate Combined

DUPLICATE RESET  
TRANSLATIONS  
100 0 0  
COMBINED: DUPLICATE  
ALL\_EXIST

The screenshot displays the 'DUPLICATE' dialog box in a software application. The dialog is divided into several sections:

- CENTROID:** 0 0 0
- SCALE FACTORS:** 1 1 1
- ROTATION ANGLES (DEGREES):** 0 0 0
- TRANSLATIONS:** FROM / TO: 100 0 0
- REPETITIONS:** 1
- CREATE NEW MATCHING BOUNDS:** Includes buttons for NODES, ELEMENTS, POINTS, CURVES, SURFACES, SOLIDS, TIES, SERVOS, SPRINGS, RBE2'S, RBE3'S, and RR0D'S.
- COMBINED:** Includes buttons for NODES, ELEMENTS, POINTS, CURVES, SURFACES, SOLIDS, TIES, SERVOS, SPRINGS, RBE2'S, RBE3'S, RR0D'S, CAVITIES, and DUPLICATE (highlighted with a red arrow).
- RESET:** Includes buttons for ALL\_EXIST (highlighted with a red arrow), UNSEL, INVIS, SURF, BOT, SELECT, SET, and END LIST (\*).

Below the dialog box, two 3D wireframe models of a rectangular frame structure are shown. The left model is the original, and the right model is the duplicate, shifted 100 units along the X-axis. A coordinate system (X, Y, Z) is visible at the bottom right of the models.

The reference model will be **completely** duplicated (e.g. nodes, elements, BCs, links) , it will be located at a distance of 100 mm from the origin (0,0,0) along X-direction referring to the global coordinate system of the model.

# Sweep

The left-hand side model is the profile with the open cross-section, named OPENED

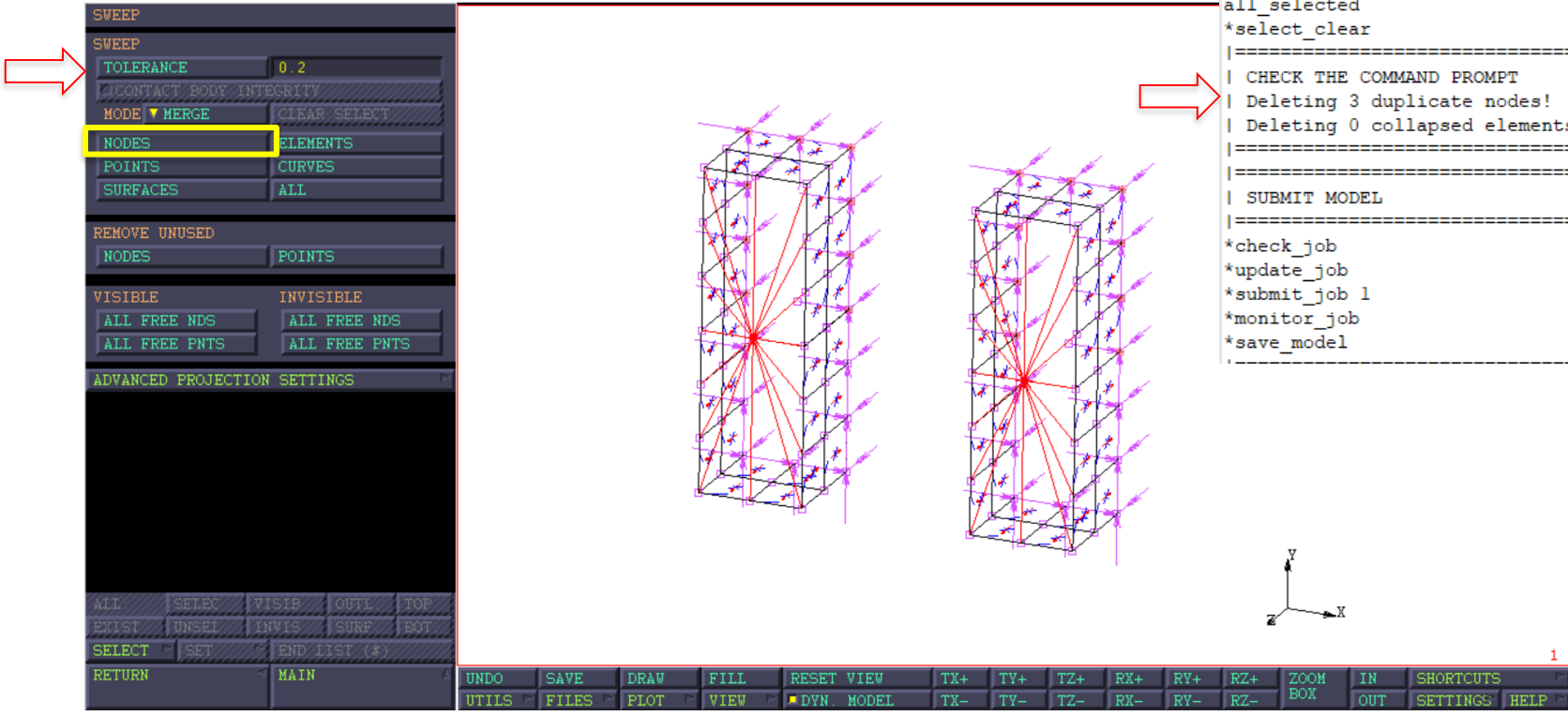
The right-hand side model is the profile with the open cross-section, named CLOSED.

Therefore, the lateral crack of the right-hand side model will be removed by the SWEEP NODES function as shown here.

Finally, the model is ready to be calculated (SUBMIT).

```

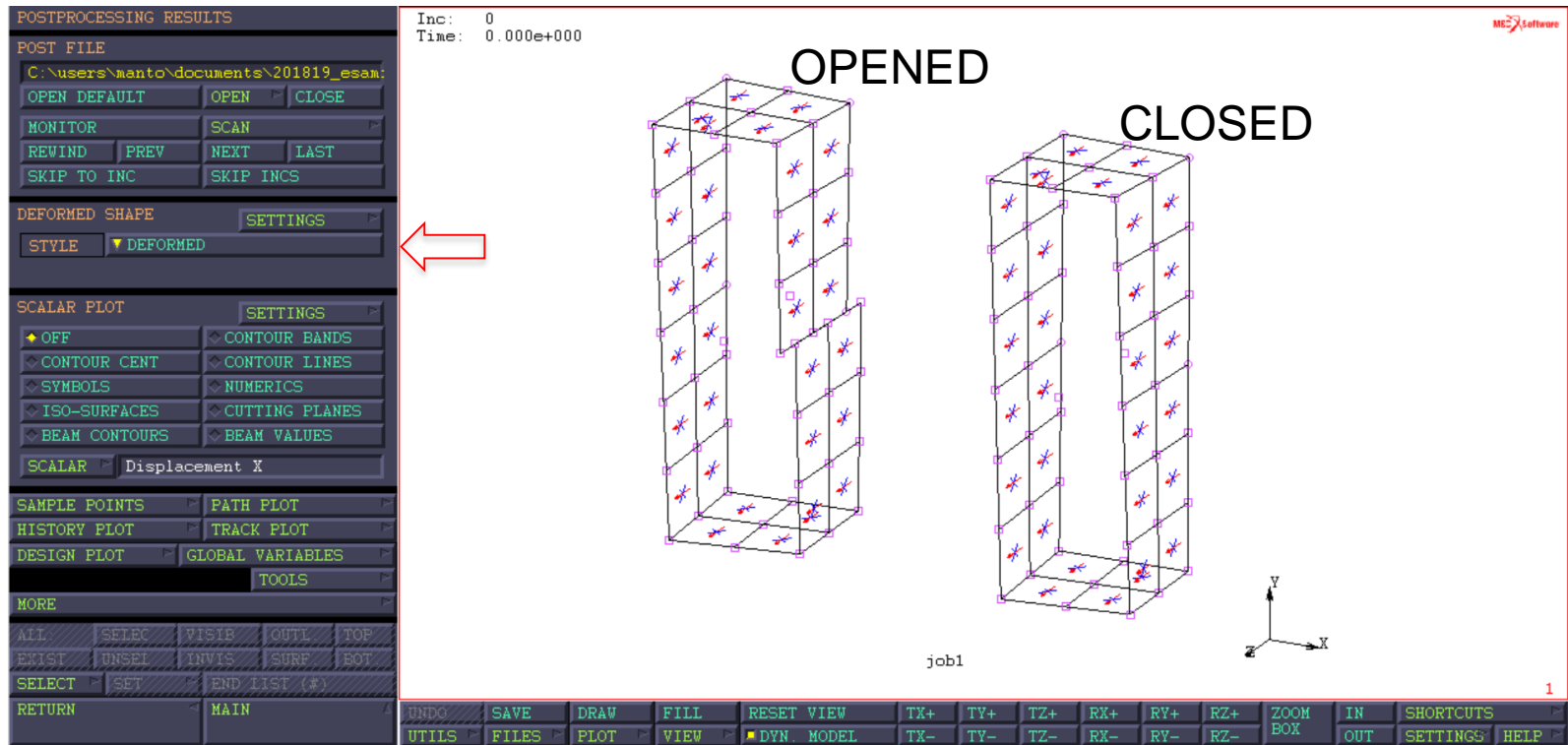
=====
| SWEEP NODES - CLOSE LATERAL CRACK
| the tolerance (t) must be:
| at least upper then the crack size;
| lower than the elements size;
| therefore 0.1 < t < 20
| I consider a tolerance value equal to 0.2
=====
*set_sweep_tolerance
0.2
*sweep_nodes
all_selected
*select_clear
=====
| CHECK THE COMMAND PROMPT
| Deleting 3 duplicate nodes!
| Deleting 0 collapsed elements!
=====
| SUBMIT MODEL
=====
*check_job
*update_job
*submit_job 1
*monitor_job
*save_model
=====
    
```



# Thin-walled profile in torsion

## Opened vs closed cross-section: RESULTS

Open the results file. Check if the **deformation** of the models is coherent with you expected!!!



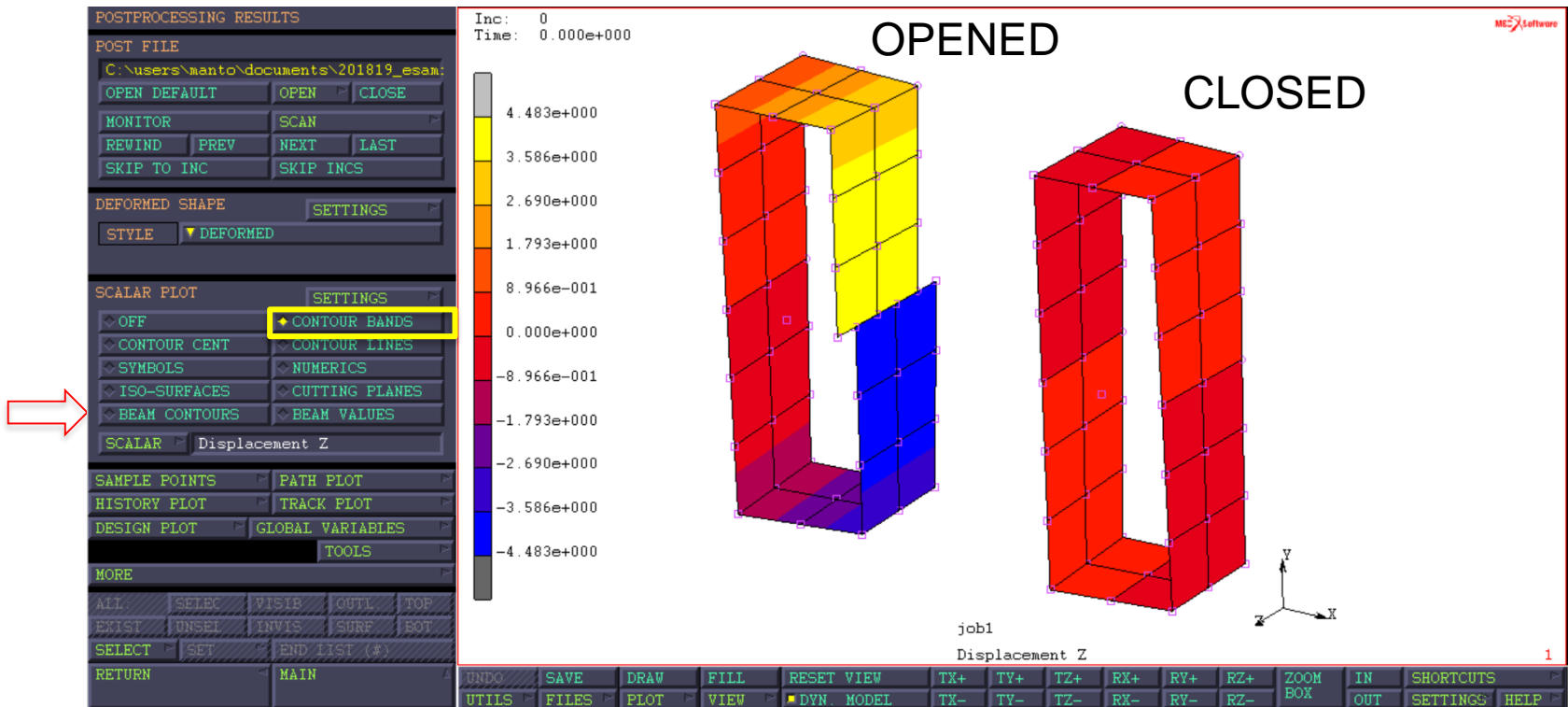


# Thin-walled profile in torsion

## Opened vs closed cross-section: RESULTS

Check the warping of the profile cross-section at their free extremity!! The simplest way is monitoring the displacement of the section along the Z direction (Displacement Z).

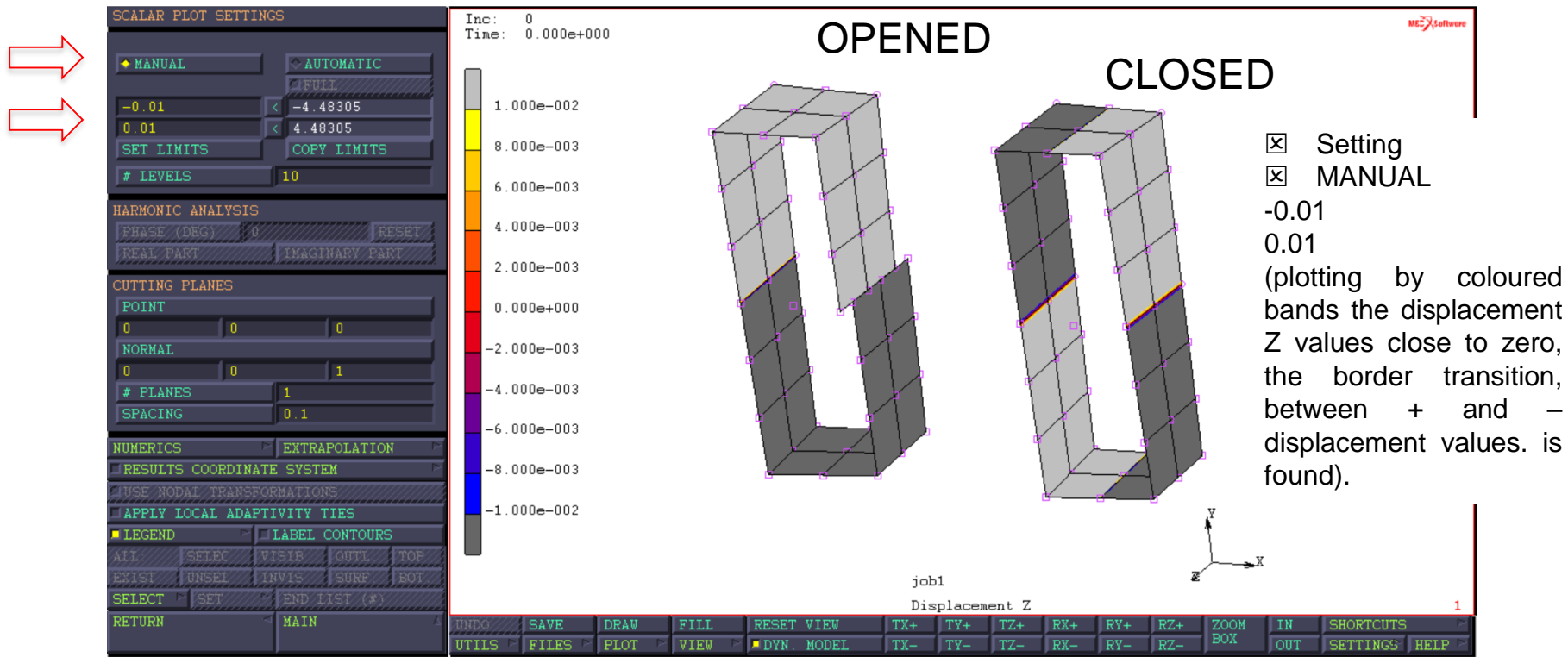
OPENED PROFILE: the maximum (minimum) Z-displacement is equal to 4.483 mm (-4.483 mm);  
CLOSED PROFILE: the maximum (minimum) Z-displacement is equal to 0.57 mm (-0.57 mm).



# Thin-walled profile in torsion

## Opened vs closed cross-section: RESULTS

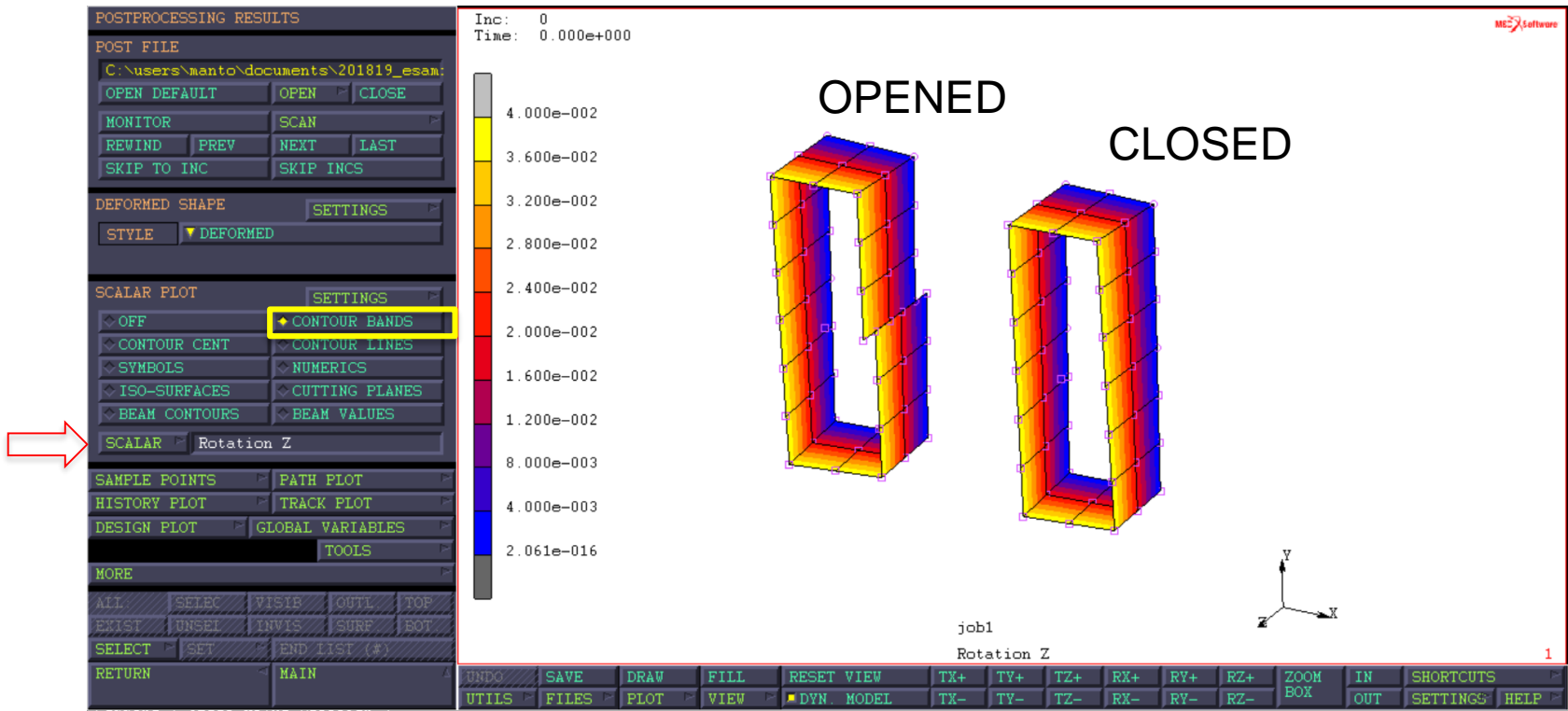
Check the warping of the profile cross-section at their free extremity!! The simplest way is monitoring the displacement of the section along the Z direction (Displacement Z).  
Some regions evidence a null deformation along the Z direction; therefore; along this segments, the warping does not occur.



# Thin-walled profile in torsion

## Opened vs closed cross-section: RESULTS

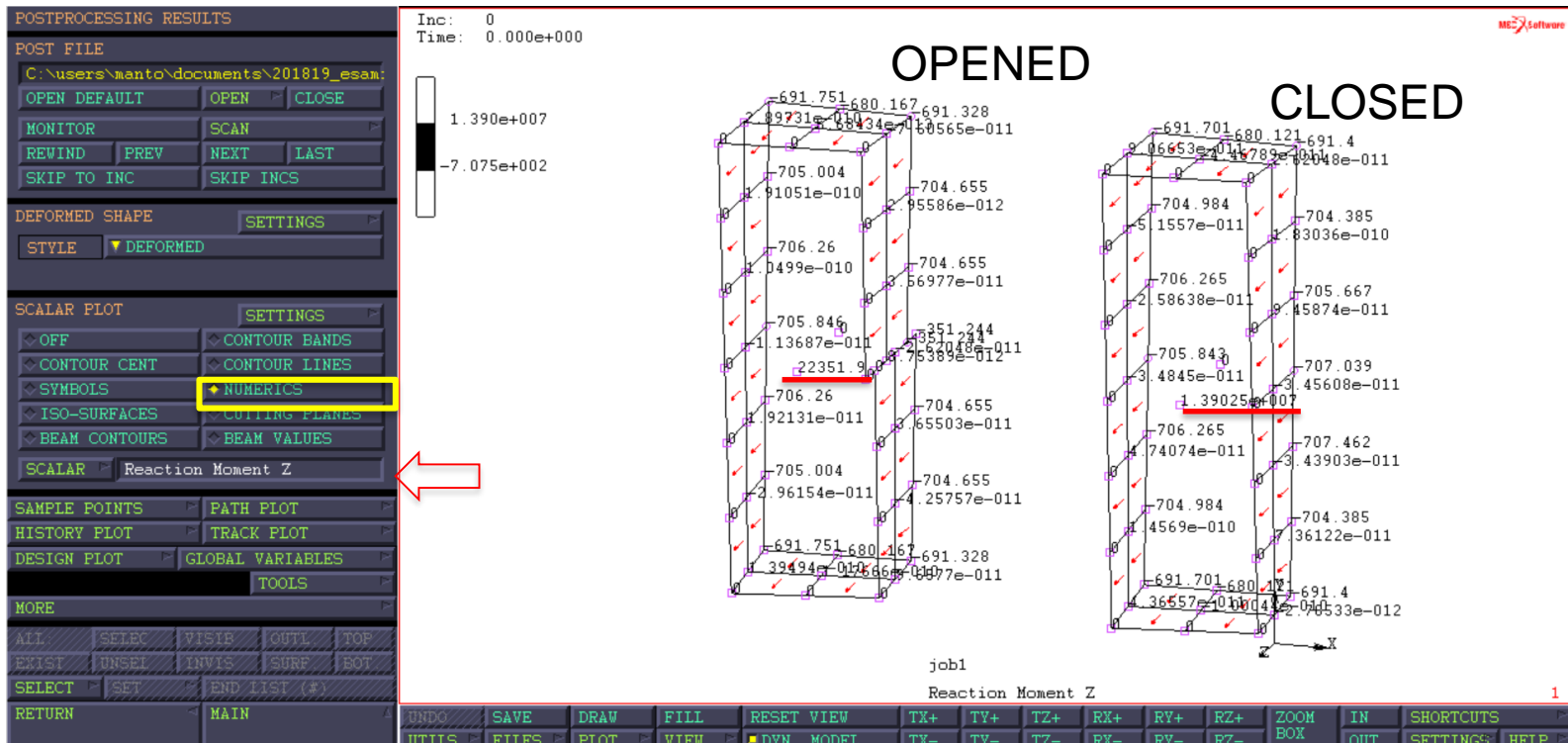
Check if the **rotation along the Z axis (Rotation Z)** of the models is coherent with you expected!!! The models do not rotate at the skew symmetry plane ( $Z=0$ ), and the maximum rotation is equal to 0.04 radians, and it is located at the free extremity of the model.



# Thin-walled profile in torsion

## Opened vs closed cross-section: RESULTS

Collect the values of **Reaction Moment Z** to compare the stiffness of the two profiles accounting the influence of the lateral crack.



For the same rotation, the reaction moment increases moving from an opened to a closed section profile. Therefore, the torsional stiffness will be increased significantly, too.

# Thin-walled profile in torsion

## Opened vs closed cross-section: RESULTS

1			input cell	
2	<b>Beam profile dimensions</b>			
3	height, at the midsurface	_h	118 mm	
4	width, at the midsurface	_b	38 mm	
5	wall thickness	_s	2 mm	
6	fillet radius	_r	0 mm	
7	section characteristic dimension	_J	120 mm	
8	modeled profile portion length (half the overall length)	_dz	40 mm	
9	profile wall perimeter	_p	312 mm	
10	profile wall midurve enclosed area	_BredtArea	4484 mm <sup>2</sup>	
11				
12	<b>Predicted torsional stiffness values</b>			
13	open thin walled section	_Kt_otw	832 mm <sup>4</sup>	
14	closed thin walled section, Bredt Formula	_Kt_ctw	515545,026 mm <sup>4</sup>	
15				
16	<b>Predicted shear stress values</b>			
17	open thin walled section	_tau_otw	53,8461538 MPa	
18	closed thin walled section, Bredt Formula	_tau_ctw	773,865878 MPa	
19				
20	<b>material properties</b>			
21	shear modulus (G12 in-plane shear modulus if ortho	_G	26923,0769 MPa	
22				
23	<b>imposed displacements</b>			
24	twist rate	_dtheta_dz	0,001 rad/mm	
25	torsional counter-rotation at the profile terminals	_theta_z	0,04 rad	
26				
27	<b>measured reaction torque (of FE models), complete section</b>			
28	open thin walled section, free warping at both ends	_Mt_otw_warp	22351,9 Nmm	
29	closed thin walled section, free warping at both ends	_Mt_ctw_warp	1,39E+07 Nmm	
32				
33	<b>results</b>			
34	profile section torsional stiffness coefficient			
35	open thin walled section, free warping at both ends	_Kt_otw_warp	830,213429 mm <sup>4</sup>	formula rigidezza tors. Sez. Sottili aperte
36	closed thin walled section, free warping at both ends	_Kt_ctw_warp	516378,571 mm <sup>4</sup>	formula di Bredt
39				
40	<b>result comparison</b>			
41	otw, free warp, FE vs theoretical ratio		ratio	relative variation
42	ctw, free warp, FE vs theoretical ratio		0,99785268	-0,21%
43			1,00161682	0,16%
44	free warp, FE, otw vs ctw ratio		0,00160776	-99,84%
45				
46	OTW constrained terminals stiffening factor		733,396266	73239,63%
47	CTW constrained terminals stiffening factor		1,21610502	21,61%
48				

The stiffness of the profiles has been analytically calculated adopting the Bredt approach for the closed section, and the formulae for the open thin section under torsion.

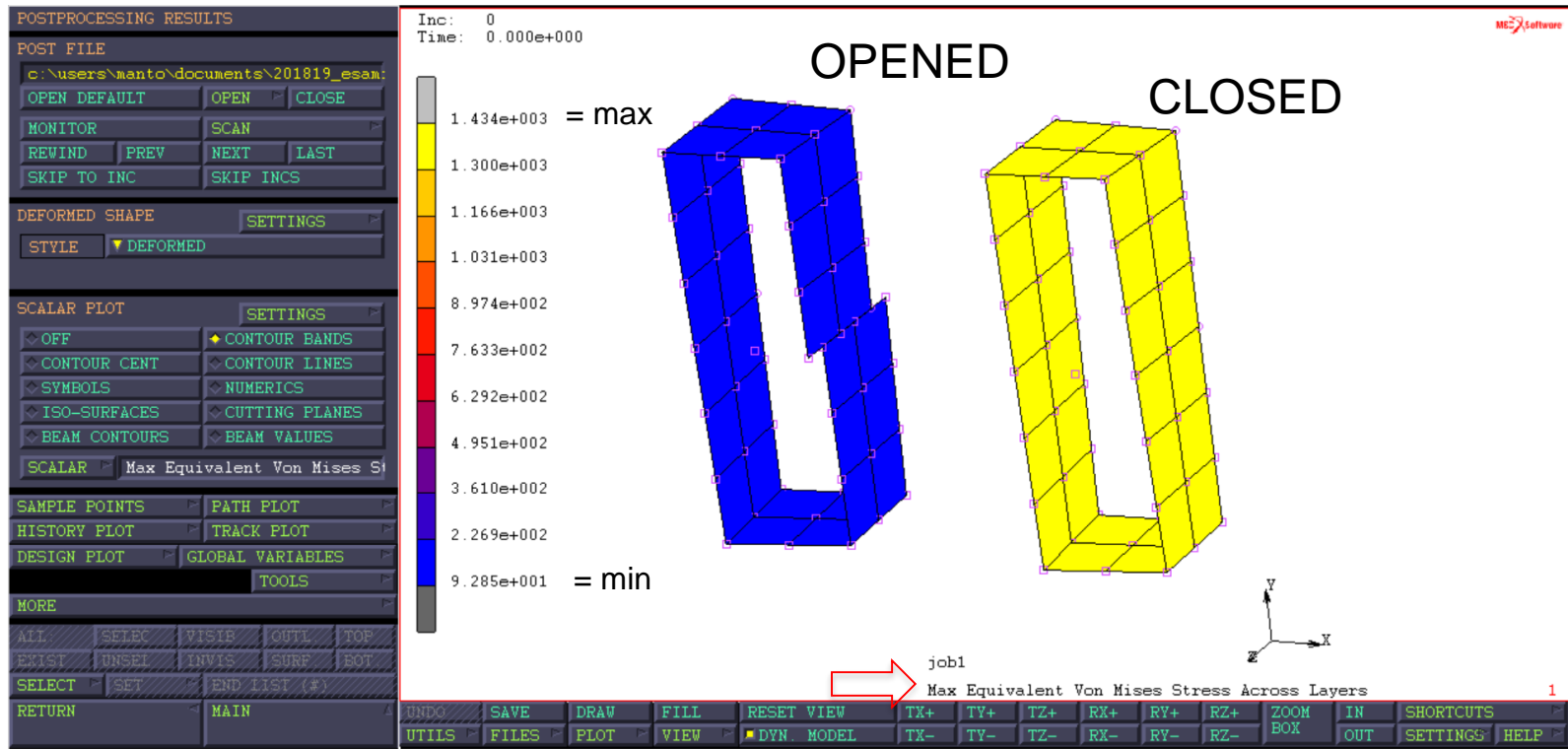
The analytical results are compared to the FE results, under the hypothesis of free warping of the structures.

Reference:

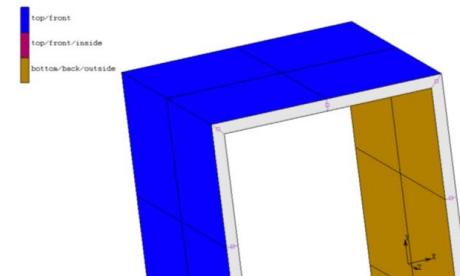
torsional\_stiffness\_evaluation\_paom2019\_v001.ods;  
spreadsheet: section\_property\_dz\_40

# Thin-walled profile in torsion

## Opened vs closed cross-section: RESULTS



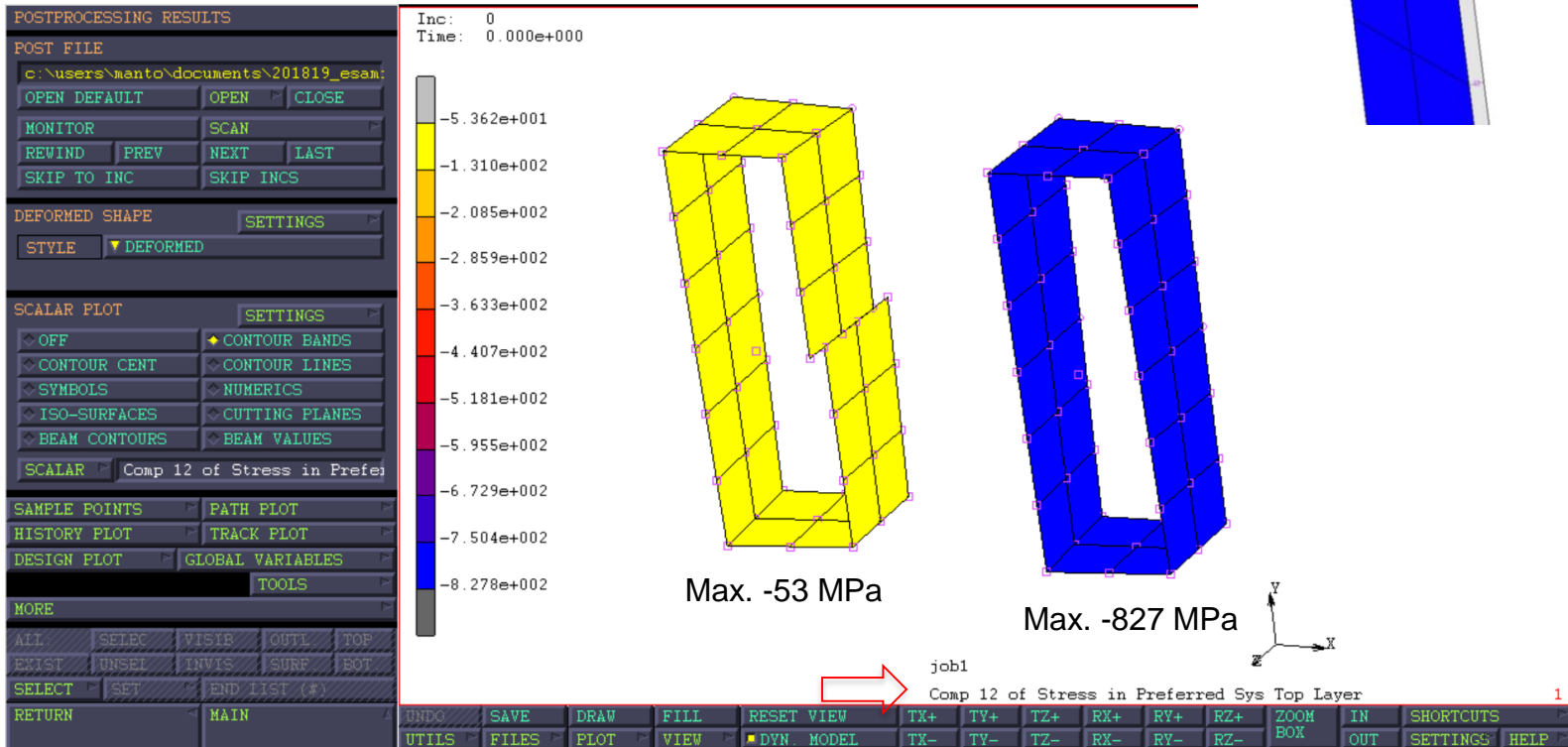
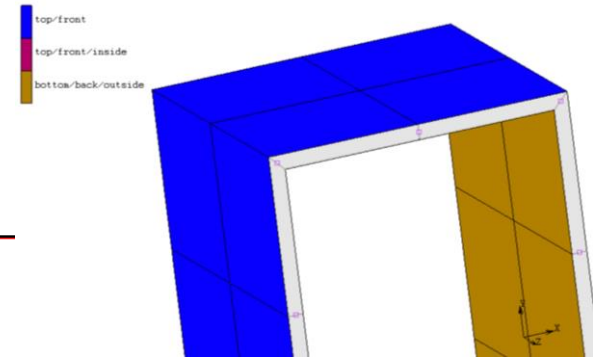
The maximum equivalent Von Mises stress occurring across the layers (top, middle, bottom) is plotted, and the opened and the closed profiles achieve the maximum stress value equal to 93 MPa and 1434 MPa, respectively.



# Thin-walled profile in torsion

## Opened vs closed cross-section: RESULTS

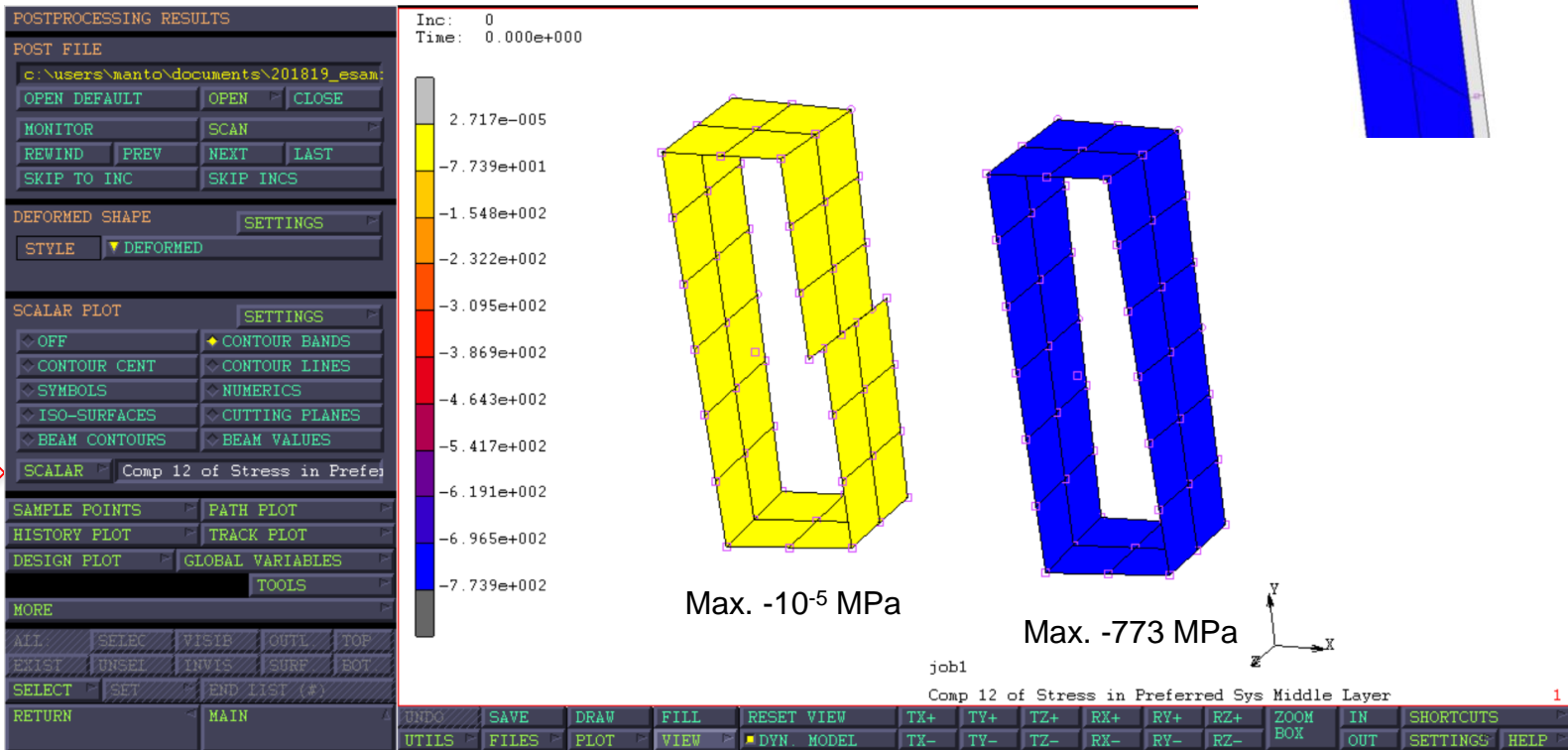
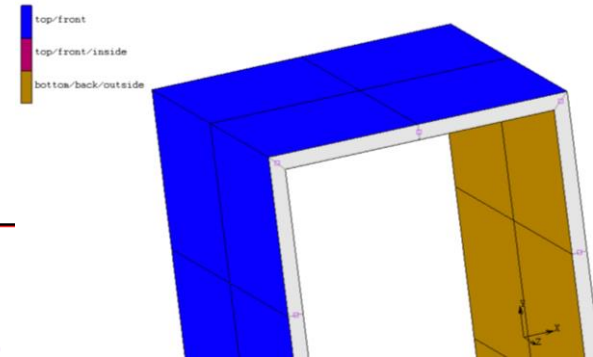
From the analysis of the components of stress at the TOP SURFACE, the stress that contributes significantly to the evaluation of the equivalent von Mises stress is the shear stress (Comp. 12 of stress in preferred system). The further stresses are negligible ( $\approx 10^{-11}$ ).



# Thin-walled profile in torsion

## Opened vs closed cross-section: RESULTS

From the analysis of the components of stress at the MIDDLE SURFACE, the stress that contributes significantly to the evaluation of the equivalent von Mises stress is the shear stress (Comp. 12 of stress in preferred system). The further stresses are negligible ( $\approx 10^{-11}$ ).

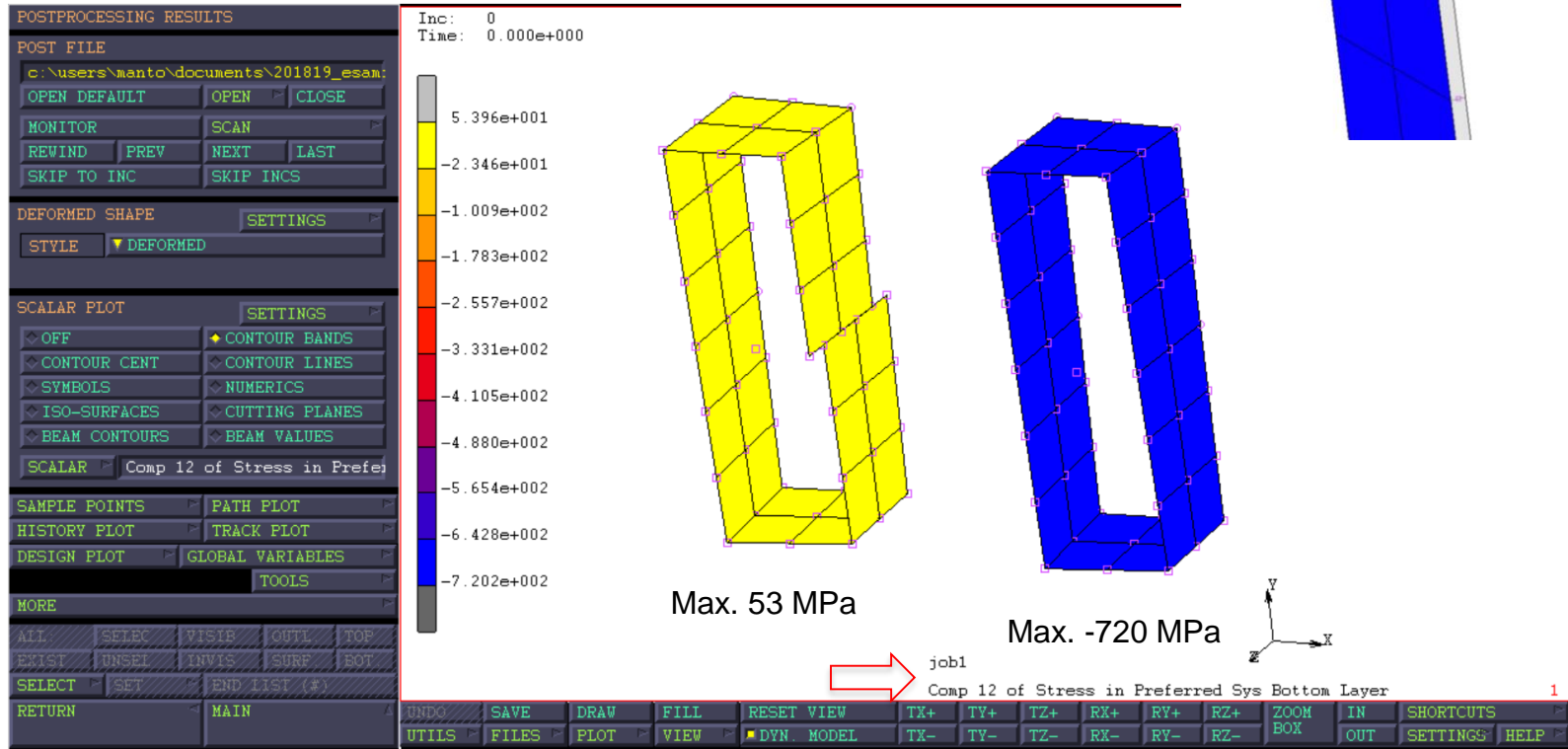
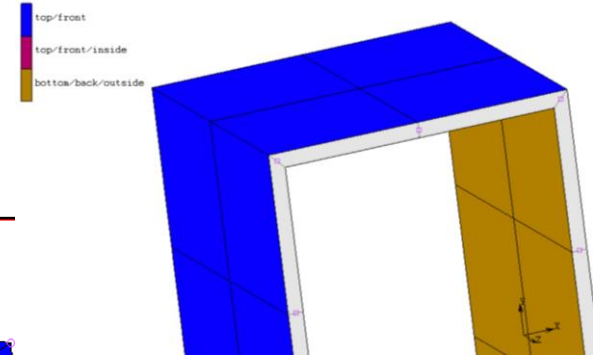




# Thin-walled profile in torsion

## Opened vs closed cross-section: RESULTS

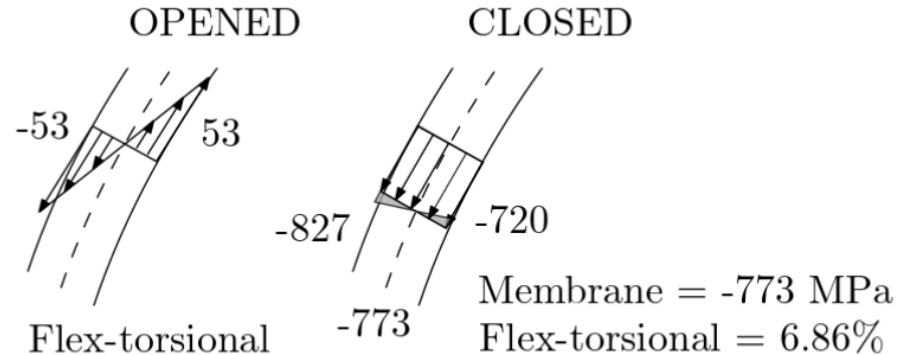
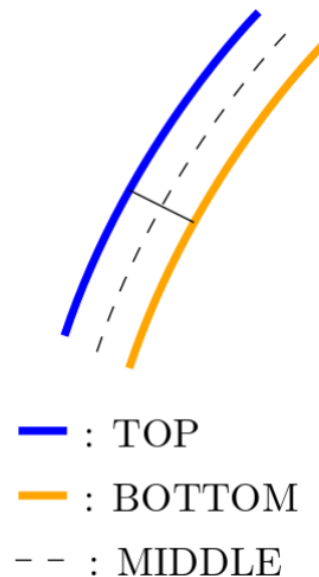
From the analysis of the components of stress at the BOTTOM SURFACE, the stress that contributes significantly to the evaluation of the equivalent von Mises stress is the shear stress (Comp. 12 of stress in preferred system). The further stresses are negligible ( $\approx 10^{-11}$ ).



# Thin-walled profile in torsion

Opened vs closed cross-section:  $\tau_{12}$

Hp) Twist rate: 0.001 rad/mm



# Thin-walled profile in torsion

## Opened vs closed cross-section: RESULTS

In the closed and the opened cases, the stiffness ( $K_t$ ) evaluated by FE and by the analytical solution are compared, and the relative error has been evaluated as follows:

$$\text{Error \%} = \frac{(FE - \text{Analytical})}{\text{Analytical}} * 100 = (\text{ratio} - 1) * 100.$$

Section	$K_t$ _Analytical [mm <sup>4</sup> ]	$K_t$ _ FE [mm <sup>4</sup> ]	FE-Analytical ratio	Error %
Closed	515545,03	516378,57	1,00162	0,16
Opened	832,00	830,21	0,99785	-0,21

The comparison of the stiffness, between the closed and the opened FE models, evidences that:

$$\text{Error \%} = \frac{(\text{Opened} - \text{Closed})}{\text{Closed}} * 100 = (\text{ratio} - 1) * 100 = -99,84\%.$$

# Agenda

MSC Marc Mentat: Select entities

- Method & Mode;
- Store;
- Identify set.

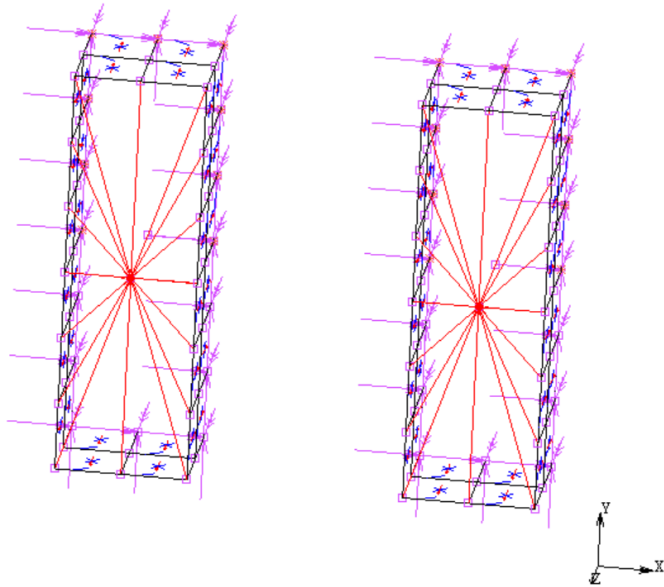
**Thin-walled profile in torsion**

- Opened vs closed cross-section;
- **Mesh convergence.**

References

# Thin-walled profile in torsion

## Mesh convergence



### GOAL:

Open the reference model named `torsione_rev01_nolabile_open_vs_close.mud` two profiles are present, characterized by an opened and a closed section, respectively. They are loaded on the free extremity by an imposed rotation.

Starting from this model, we will compare the influence of the mesh size on the evaluation of torsional stiffness by FE.

The element size under investigation is in the range of [20, 10, 5, 2.5, 1.25] mm

The new models is called `torsione_rev01_nolabile_open_vs_close_convergence.mud`

# Thin-walled profile in torsion

## Duplicate Combined

```

=====
|
|      DUPLICATE MODEL
| the opened and the closed profiles will be duplicated four times
| and with a distance of 200 mm defined along the Y direction
| from the reference models.
| left-hand side: closed section profiles
| right-hand side: opened section profiles
|=====
|
|*set_duplicate_translations
|*set_duplicate_translation y -200
|*set_duplicate_repetitions 4
|*duplicate_combined
|all_existing
|=====
  
```

DUPLICATE

CENTROID  
0 0 0

SCALE FACTORS  
1 1 1

ROTATION ANGLES (DEGREES)  
0 0 0

TRANSLATIONS FROM / TO  
0 -200 0

REPETITIONS 4

CREATE NEW MATCHING BOUND'S

NODES ELEMENTS POINTS

CURVES SURFACES SOLIDS

TIES SERVOS SPRINGS

RBE2'S RBE3'S RR0D'S

COMBINED

■ NODES ■ ELEMENTS ■ POINTS

■ CURVES ■ SURFACES ■ SOLIDS

■ TIES ■ SERVOS ■ SPRINGS

■ RBE2'S ■ RBE3'S ■ RR0D'S

■ CAVITIES

DUPLICATE

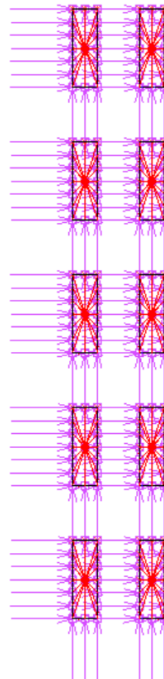
RESET

ALL SELEC VISIB OUTL TOP

ERASE NSEL INVIS SURF BOT

SELECT SET END LIST (\*)

RETURN MAIN



# Thin-walled profile in torsion

## Duplicate Combined

```

=====
| Model_0: avg. element size = 20 mm (reference mesh) --> y-coordinate range [-59, +59]
| Model_1: avg. element size = 10 mm --> y-coordinate range [-259, -141]
| Model_2: avg. element size = 5 mm --> y-coordinate range [-459, -341]
| Model_3: avg. element size = 2.5 mm --> y-coordinate range [-659, -541]
| Model_4: avg. element size = 1.25 mm --> y-coordinate range [-859, -741]
=====
  
```

The screenshot displays a software interface with a 'DUPLICATE' dialog box on the left and a 3D model of a thin-walled profile in torsion on the right. The dialog box contains the following settings:

- CENTROID:** 0, 0, 0
- SCALE FACTORS:** 1, 1, 1
- ROTATION ANGLES (DEGREES):** 0, 0, 0
- TRANSLATIONS:** FROM / TO, 0, -200, 0
- REPETITIONS:** 4
- CREATE NEW MATCHING BOUND'S:**
  - NODES, ELEMENTS, POINTS
  - CURVES, SURFACES, SOLIDS
  - TIES, SERVOS, SPRINGS
  - RBE2'S, RBE3'S, RR0D'S
- COMBINED:**
  - NODES, ELEMENTS, POINTS
  - CURVES, SURFACES, SOLIDS
  - TIES, SERVOS, SPRINGS
  - RBE2'S, RBE3'S, RR0D'S
  - CAVITIES
- RESET:** ALL, SELEC, VISIB, OUTL, TOP, EXIST, UNSEL, INVIS, SURF, BOT, SELECT, SET, END LIST (\*), RETURN, MAIN

The 3D model shows five horizontal sections labeled Model\_0 to Model\_4, each representing a different mesh density. A coordinate system (X, Y, Z) is visible in the bottom right of the model area.

All the models are the same element size (20 mm), the elements size that we want to assess for the different models is shown above.

# Thin-walled profile in torsion

## Subdivide

MESH GENERATION

NODES	ADD	REM	EDIT	SHOW
ELEMS	ADD	REM	EDIT	SHOW
PTS	ADD	REM	EDIT	SHOW
CRVS	ADD	REM	EDIT	SHOW
SRFS	ADD	REM	EDIT	SHOW
SOLIDS	ADD	REM		SHOW

BETWEEN NODE BETWEEN POINT

ELEMENT CLASS ▾ QUAD (4)

CURVE TYPE ▾ LINE

SURFACE TYPE ▾ QUAD

SOLID TYPE ▾ BLOCK

COORDINATE SYSTEM

SET ▾ RECTANGULAR GRID

CLEAR MESH CLEAR GEOM

ATTACH ▾ AUTOMESH ▾

CHANGE CLASS ▾ CHECK ▾

CONVERT ▾ DUPLICATE ▾

ELEMENT TYPES ▾ EXPAND ▾

INTERSECT ▾ MOVE ▾

RELAX ▾ RENUMBER ▾

REVOLVE ▾ SOLIDS ▾

STRETCH ▾ **SUBDIVIDE ▾**

SWEEP ▾ SYMMETRY ▾

ALL SELEC VISIB OUTL TOP

EXIST UNSEL INVIS SURF BOT

SELECT ▾ SET END LIST (#)

RETURN MAIN

Model\_0

Model\_1

Model\_2

Model\_3

Model\_4

MAIN MENU  
MESH GENERATION  
SUBDIVIDE

The mesh refinement is performed setting the number of element divisions along the X, Y and Z axis of the elements.

Y  
Z X

1

UNDO SAVE DRAW FILL RESET VIEW TX+ TY+ TZ+ RX+ RY+ RZ+ ZOOM IN SHORTCUTS

UTILS FILES PLOT VIEW ▾ DYN MODEL TX- TY- TZ- RX- RY- RZ- ZOOM OUT SETTINGS HELP



# Thin-walled profile in torsion

## Subdivide

SUBDIVIDE

DIVISIONS 2  
2  
2

BIAS FACTORS 0  
0  
0

ELEMENTS CURVES

RESET REFINE

ELEMENTS TO QUAD

ELEMENTS TO HEX

ADVANCED PROJECTION SETTINGS

REFINE SKIN

THICKNESS 0.1

DIVISIONS 1

DIRECTION INWARD

REFINE SKIN 2-D

REFINE SKIN 3-D

ALL SELEC VISIB OUTL TOP

EXIST UNSE UNVIS SURF BOT

SELECT REFINE END LIST (#)

RETURN MAIN

Command > \*sub divisions  
Enter number of divisions in the U,V and W : 2  
Enter number of divisions in the U,V and W : 2  
Enter number of divisions in the U,V and W : 2  
Command >

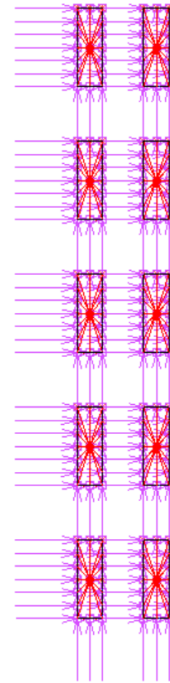
Model\_0

Model\_1

Model\_2

Model\_3

Model\_4



DIVISIONS

2

2

2

ELEMENTS

Select the elements of Model\_1, Model\_2, Model\_3 and Model\_4 using the METHOD and the MODE that you prefer.

SELEC

1

# Thin-walled profile in torsion

## Subdivide

SUBDIVIDE

DIVISIONS 2

BIAS FACTORS 0

**ELEMENTS** CURVES

RESET REFINE

ELEMENTS TO QUAD

ELEMENTS TO HEX

ADVANCED PROJECTION SETTINGS

REFINE SKIN

THICKNESS 0.1

DIVISIONS 1

DIRECTION INWARD

REFINE SKIN 2-D

REFINE SKIN 3-D

ALL SELEC VISIB OUTL TOP

EXIST UNSEL INVIS SURF BOT

SELECT SET END LIST (\*)

RETURN MAIN

Command > \*sub\_divisions  
 Enter number of divisions in the U,V and W : 2  
 Enter number of divisions in the U,V and W : 2  
 Enter number of divisions in the U,V and W : 2  
 Command >

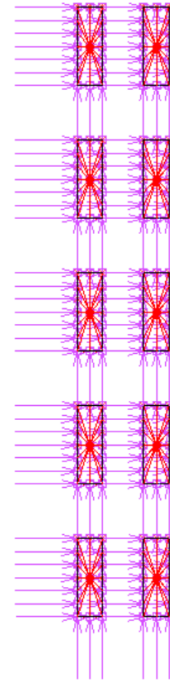
Model\_0

Model\_1

**Model\_2**

**Model\_3**

**Model\_4**



DIVISIONS

2

2

2

ELEMENTS

Select the elements of Model\_2, Model\_3 and Model\_4 using the METHOD and the MODE that you prefer.

SELEC

# Thin-walled profile in torsion

## Subdivide

**SUBDIVIDE**

DIVISIONS	2
BIAS FACTORS	0
ELEMENTS	CURVES
RESET	REFINE
ELEMENTS TO QUAD	
ELEMENTS TO HEX	
ADVANCED PROJECTION SETTINGS	
REFINE SKIN	
THICKNESS	0.1
DIVISIONS	1
DIRECTION	INWARD
REFINE SKIN 2-D	
REFINE SKIN 3-D	

Model\_0  
Model\_1  
Model\_2  
**Model\_3**  
**Model\_4**

DIVISIONS  
2  
2  
2  
2  
ELEMENTS  
Select the elements of Model\_3 and Model\_4 using the METHOD and the MODE that you prefer.  
SELEC

Command > \*sub\_divisions  
Enter number of divisions in the U, V and W : 2  
Enter number of divisions in the U, V and W : 2  
Enter number of divisions in the U, V and W : 2  
Command >

# Thin-walled profile in torsion

## Subdivide

SUBDIVIDE  
 DIVISIONS 2  
 2  
 2  
 BIAS FACTORS 0  
 0  
 0  
**ELEMENTS** CURVES  
 RESET REFINE  
 ELEMENTS TO QUAD  
 ELEMENTS TO HEX  
 ADVANCED PROJECTION SETTINGS  
 REFINE SKIN  
 THICKNESS 0.1  
 DIVISIONS 1  
 DIRECTION INWARD  
 REFINE SKIN 2-D  
 REFINE SKIN 3-D  
 ALL SELEC VISIB OUTL TOP  
 EXIST UNSEL INVIS SURF BOT  
 SELECT SET END LIST (\*)  
 RETURN MAIN  
 Command > \*sub\_divisions  
 Enter number of divisions in the U,V and W : 2  
 Enter number of divisions in the U,V and W : 2  
 Enter number of divisions in the U,V and W : 2  
 Command >

DIVISIONS  
 2  
 2  
 2  
 2  
 ELEMENTS  
 Select the elements of Model\_4 using the METHOD and the MODE that you prefer.  
 SELEC

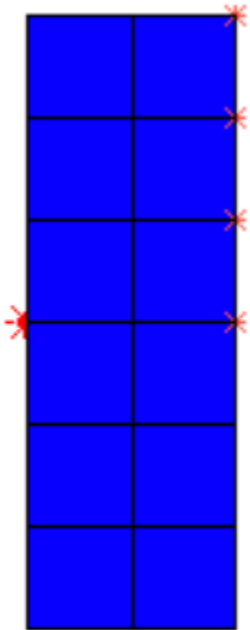
Model\_0  
 Model\_1  
 Model\_2  
 Model\_3  
**Model\_4**

UNDO SAVE DRAW FILL RESET VIEW TX+ TY+ TZ+ RX+ RY+ RZ+ ZOOM IN SHORTCUTS  
 UTILS FILES PLOT VIEW DYN MODEL TX- TY- TZ- RX- RY- RZ- BOX OUT SETTINGS HELP  
 Ready

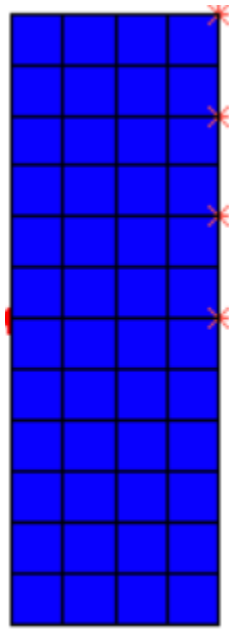
# Thin-walled profile in torsion

Subdivide

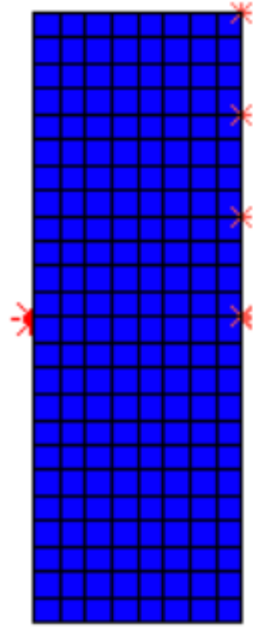
Detailed view of the models



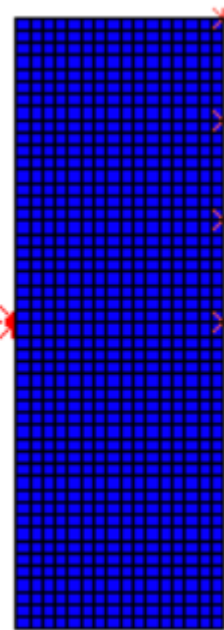
Model\_0  
20 mm



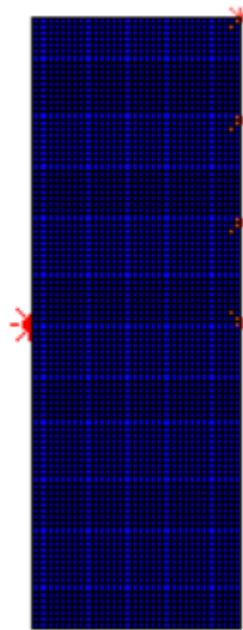
Model\_1  
10 mm



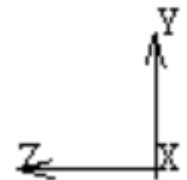
Model\_2  
5 mm



Model\_3  
2.5 mm



Model\_4  
1.25 mm



# Thin-walled profile in torsion

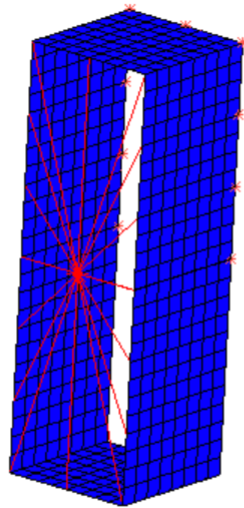
## Sweep

```
=====
| SWEEP NODES - DUPLICATE DUE TO THE ELEMENTS SUBDIVIDE;
| WITHOUT REMOVING THE LATERAL CRACK OF THE OPENED SECTION (left-hand side models)
| the tolerance (t) must be:
| lower then the crack size (0.1);
| lower than the minimum elements size (1.25);
| therefore t < 0.1
| I consider a tolerance value equal to 0.05
|=====
|
*set_sweep_tolerance
0.05
*sweep_nodes
all_existing
*select_clear
|=====
| CHECK THE COMMAND PROMPT
| Deleting 42191 duplicate nodes!
| Deleting 0 collapsed elements!
|=====
```

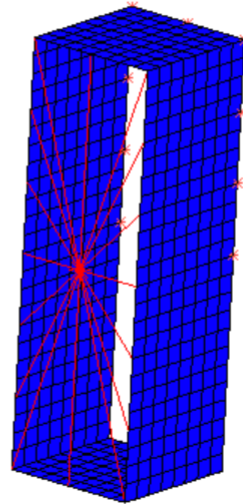
# Thin-walled profile in torsion

## Update Links (RBE2) and BCs

Detailed view of the Model\_2: RBE2 tied nodes

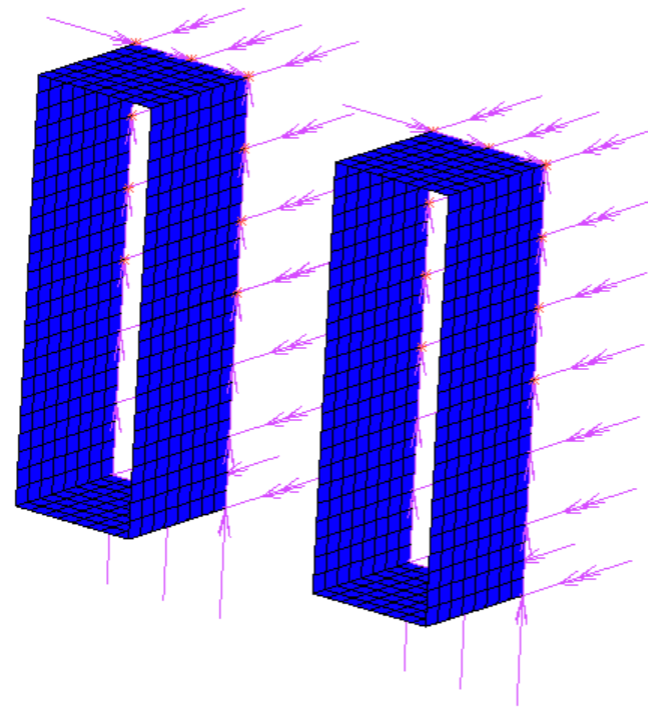


rbe2\_4



rbe2\_8

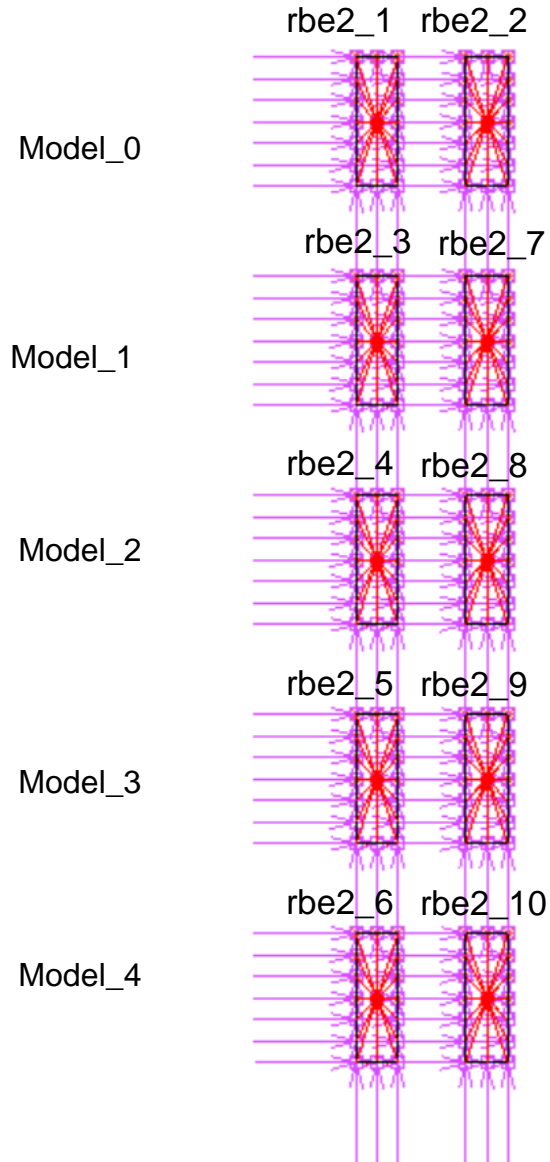
Detailed view of the Model\_2: BCs skew-symm



The refinement of the mesh by subdividing the elements required that both the tied nodes of the RBE2, and the nodes involved in the skew-symmetry BCs must be updated.

# Thin-walled profile in torsion

## Update Links (RBE2) and BCs



Make visible the labels of the RBE2 on the screen, as follows:

```
PLOT
RBE2: SETTING
 LABELS
REGEN
RESET VIEW
FILL
```

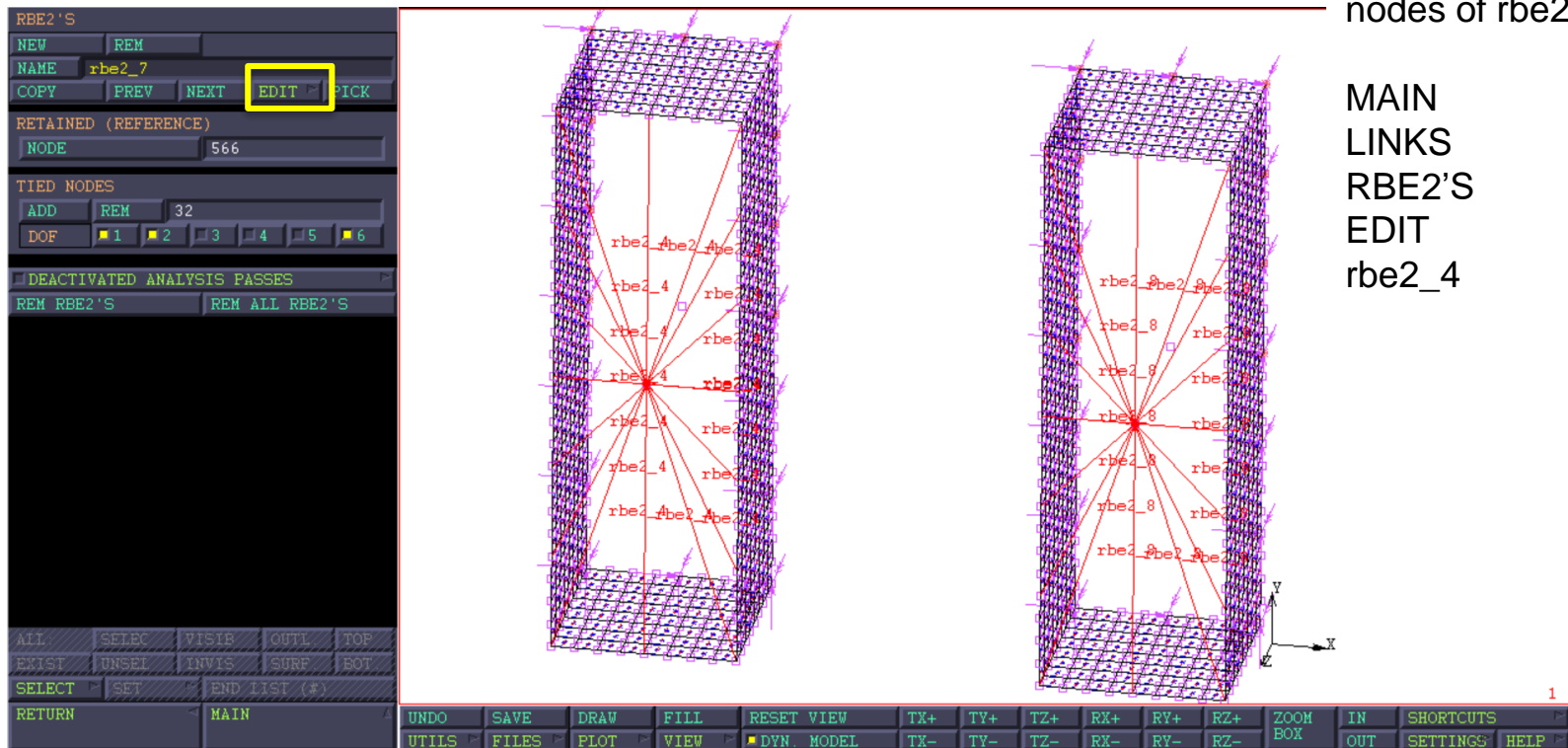


# Thin-walled profile in torsion

## Update Links (RBE2) and BCs

As an example, the upload procedure adopted for the tied nodes of rbe2\_4 is:

MAIN  
LINKS  
RBE2'S  
EDIT  
rbe2\_4



# Thin-walled profile in torsion

## Update Links (RBE2) and BCs

As an example, the upload procedure adopted for the tied nodes of rbe2\_4 is:

**TIED NODES: ADD**  
*Select the tied nodes of the RBE2\_4 using the METHOD and the MODE that you prefer.*  
**SELEC**

The screenshot displays the software interface for defining RBE2 links. The left panel shows the 'RBE2'S' section with 'NAME' set to 'rbe2\_4' and 'NODE' set to '367'. The 'TIED NODES' section has 'ADD' and 'REM' buttons, and 'DOF' options 1 through 6. The 'SELEC' button is highlighted in yellow. The 3D model shows a rectangular profile with a grid of nodes and red lines representing RBE2 links. The left view shows a central node connected to nodes on the front face, labeled 'rbe2\_4'. The right view shows a similar setup for the back face, labeled 'rbe2\_8'. A coordinate system (X, Y, Z) is visible at the bottom right of the model. The bottom of the interface has a menu bar with options like UNDO, SAVE, DRAW, FILL, RESET VIEW, TX+, TY+, TZ+, RX+, RY+, RZ+, ZOOM BOX, IN, SHORTCUTS, UTILS, FILES, PLOT, VIEW, DYN MODEL, TX-, TY-, TZ-, RX-, RY-, RZ-, OUT, SETTINGS, HELP.

# Thin-walled profile in torsion

## Update Links (RBE2) and BCs

The number of tied nodes is function of the mesh refinement.

As an example, the tied nodes of RBE2\_4 are 367.

If you adopt the BOX METHOD, keep in mind to remove the retained node of RBE2. The retained node should not be included in the tied nodes, it generates an internal conflict based on the kinematic definition applied to the RBE2.

The screenshot displays the software interface for defining RBE2 elements. On the left, a panel titled 'RBE2'S' contains the following information:

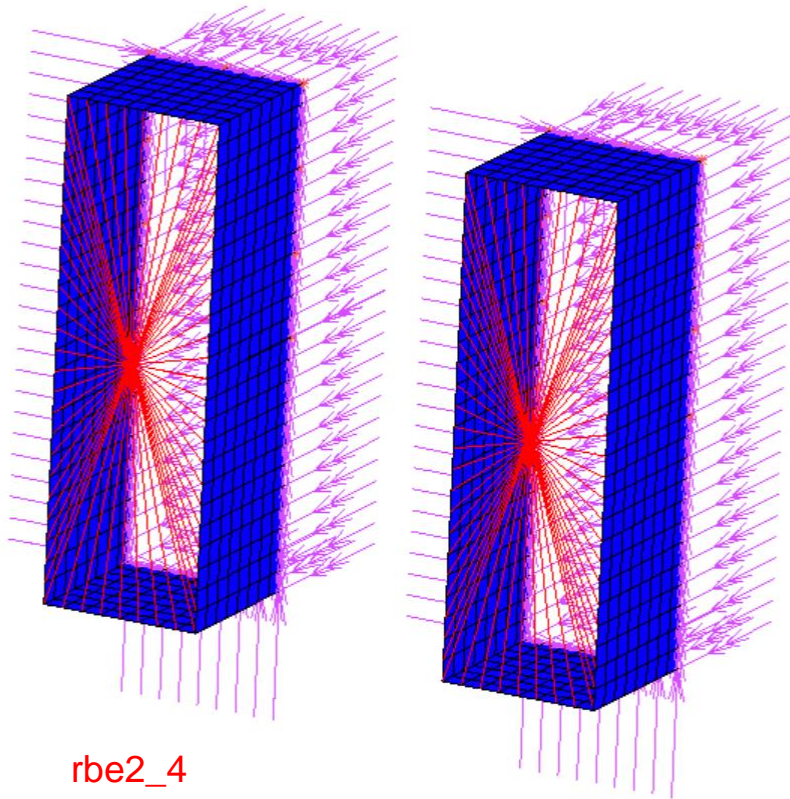
- NEW REM** (highlighted with a red arrow)
- NAME** rbe2\_4
- COPY** PREV NEXT EDIT PICK
- RETAINED (REFERENCE)**
  - NODE** 367
- TIED NODES**
  - ADD REM** 17
  - DOF** 1 2 3 4 5 6
- DEACTIVATED ANALYSIS PASSES**
  - REM RBE2'S
  - REM ALL RBE2'S
- SELECT** (highlighted with a yellow box)

At the bottom of the interface, a menu bar includes: UNDO, SAVE, DRAW, FILL, RESET VIEW, TX+, TY+, TZ+, RX+, RY+, RZ+, ZOOM BOX, IN, SHORTCUTS, UTILS, FILES, PLOT, VIEW, DYN MODEL, TX-, TY-, TZ-, RX-, RY-, RZ-, OUT, SETTINGS, HELP.

Two 3D models of a thin-walled profile are shown. The left model shows a central node connected to 17 other nodes, labeled 'rbe2\_4'. The right model shows a similar setup but with a different set of tied nodes, labeled 'rbe2\_8'. A coordinate system (X, Y, Z) is visible in the bottom right of the right model.

# Thin-walled profile in torsion

## Update Links (RBE2) and BCs



rbe2\_4

rbe2\_8



Keep in mind also to update the skew-symmetry BCs.

After the update of RBE2 and BCs, the Models\_2 becomes as shown here. Similarly, this procedure must be accomplished for any models.

The models are ready to be computed.

# Thin-walled profile in torsion

## Mesh Convergence: RESULTS

The stiffness ( $K_t$ ) evaluated by FE and by the analytical solution are compared, and the relative error has been evaluated as follows:

$$\_Kt\_ratio = \frac{Kt\_Opened}{Kt\_Closed}$$

	Element size [mm]	_Mt_ow_warp [Nmm]	_Mt_cw_warp [Nmm]	_Kt_ow_warp [mm <sup>4</sup> ]	_Kt_cw_warp [mm <sup>4</sup> ]	_Kt_ratio
Analytical*	/	/	/	832,0	515545,0	0,00161
Model_0	20,00	22351,9	1,39025E+07	830,2	516378,6	0,00161
Model_1	10,00	22309,4	1,39024E+07	828,6	516374,9	0,00160
Model_2	5,00	22234,7	1,39024E+07	825,9	516374,9	0,00160
Model_3	2,50	22129,0	1,39023E+07	821,9	516371,1	0,00159
Model_4	1,25	22038,4	1,39022E+07	818,6	516367,4	0,00159

\* exact solution for profile with infinitesimal thickness ( $t \rightarrow 0$ )

The influence of the mesh size on the torsional stiffness evaluation for closed section is negligible, and it is of limited relevance for the opened section.

	Error_Kt_ow_warp [%]	Error_Kt_cw_warp [%]
Model_0	1,42%	0,0022%
Model_1	1,23%	0,0014%
Model_2	0,89%	0,0014%
Model_3	0,41%	0,0007%

Relative error evaluated for the FE models referring to the Model\_4.

# Agenda

MSC Marc Mentat: Select entities

- Method & Mode;
- Store;
- Identify set.

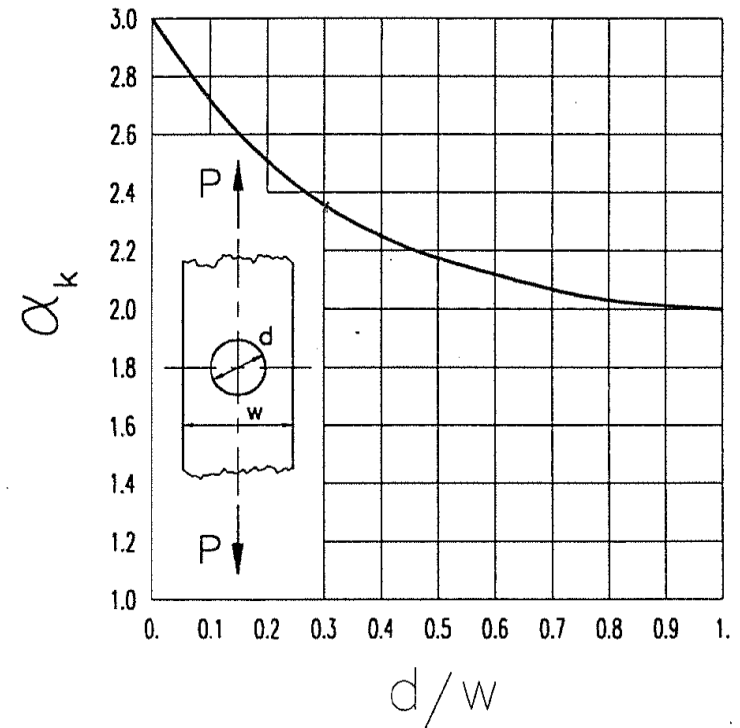
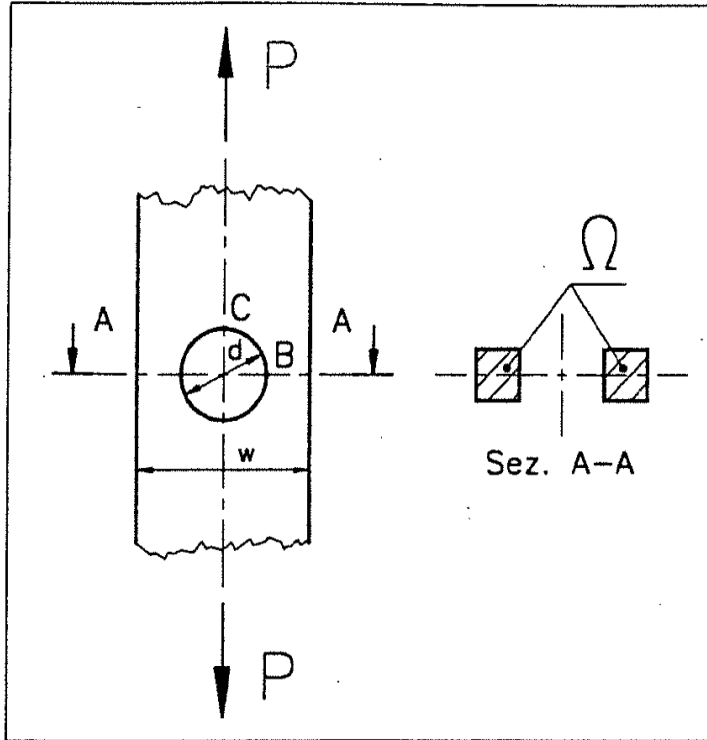
**Thin-walled profile in torsion**

- Opened vs closed cross-section;
- **Mesh convergence: Critical aspects**

References

# Mesh convergence

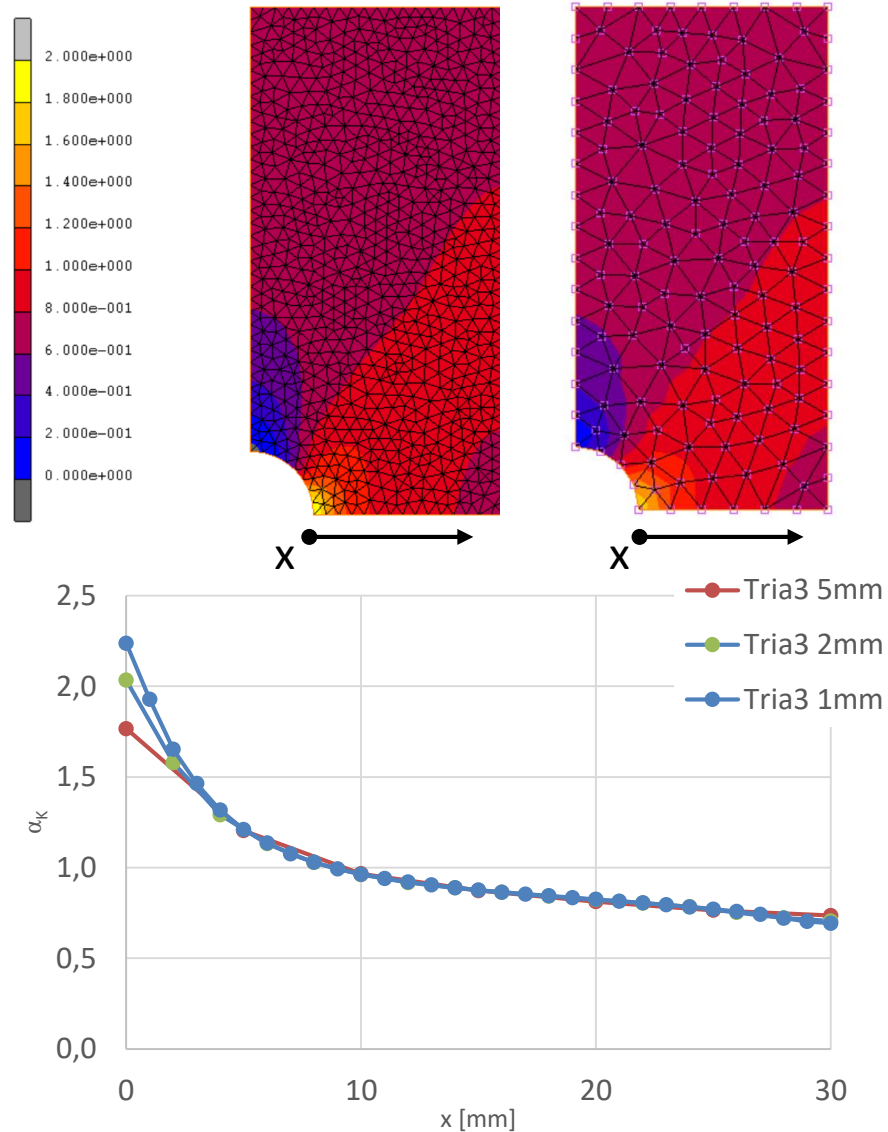
Critical Aspects: Case A



$d/w = 0.25; \alpha_k \approx 2,42$  (theory),

# Mesh Convergence

## Critical Aspects: Case A





# Mesh Convergence

## Critical Aspects: Case B

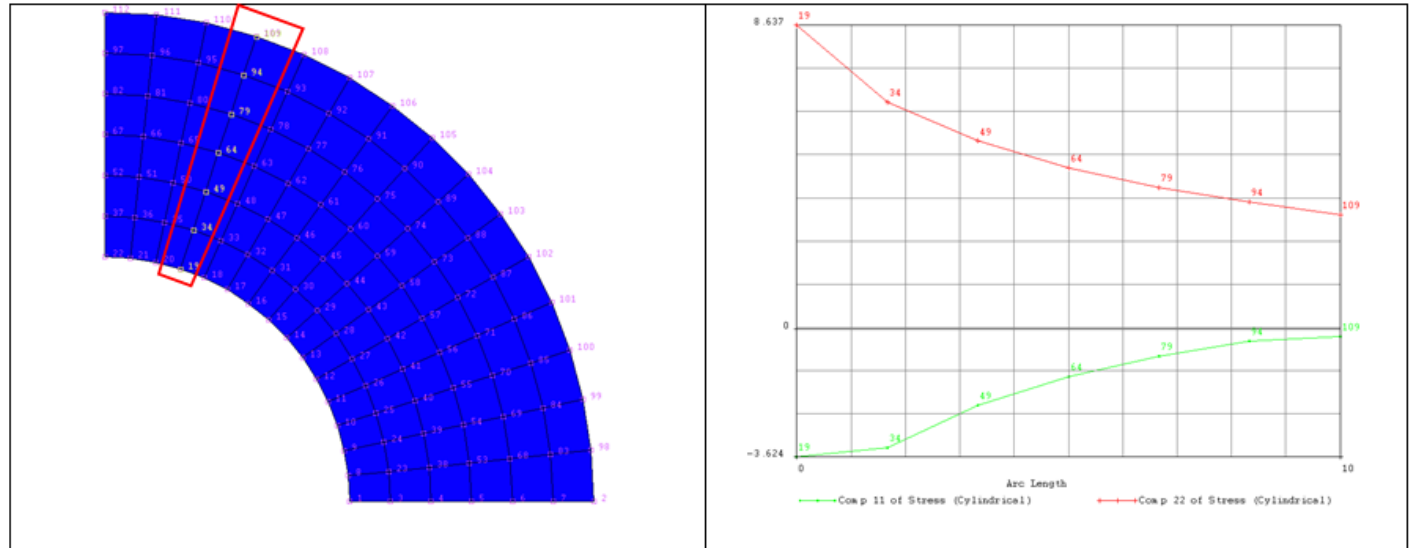
Pressure Vessel

$$R_{\text{int}} = 10 \text{ mm}$$

$$R_{\text{est}} = 20 \text{ mm}$$

$$p_i = 5 \text{ MPa}$$

*MESH 1: 90 Elementi, 112 Nodi*



Lamè solution:

$$\sigma_R \Big|_{r=R_i} = -5 \text{ MPa}$$

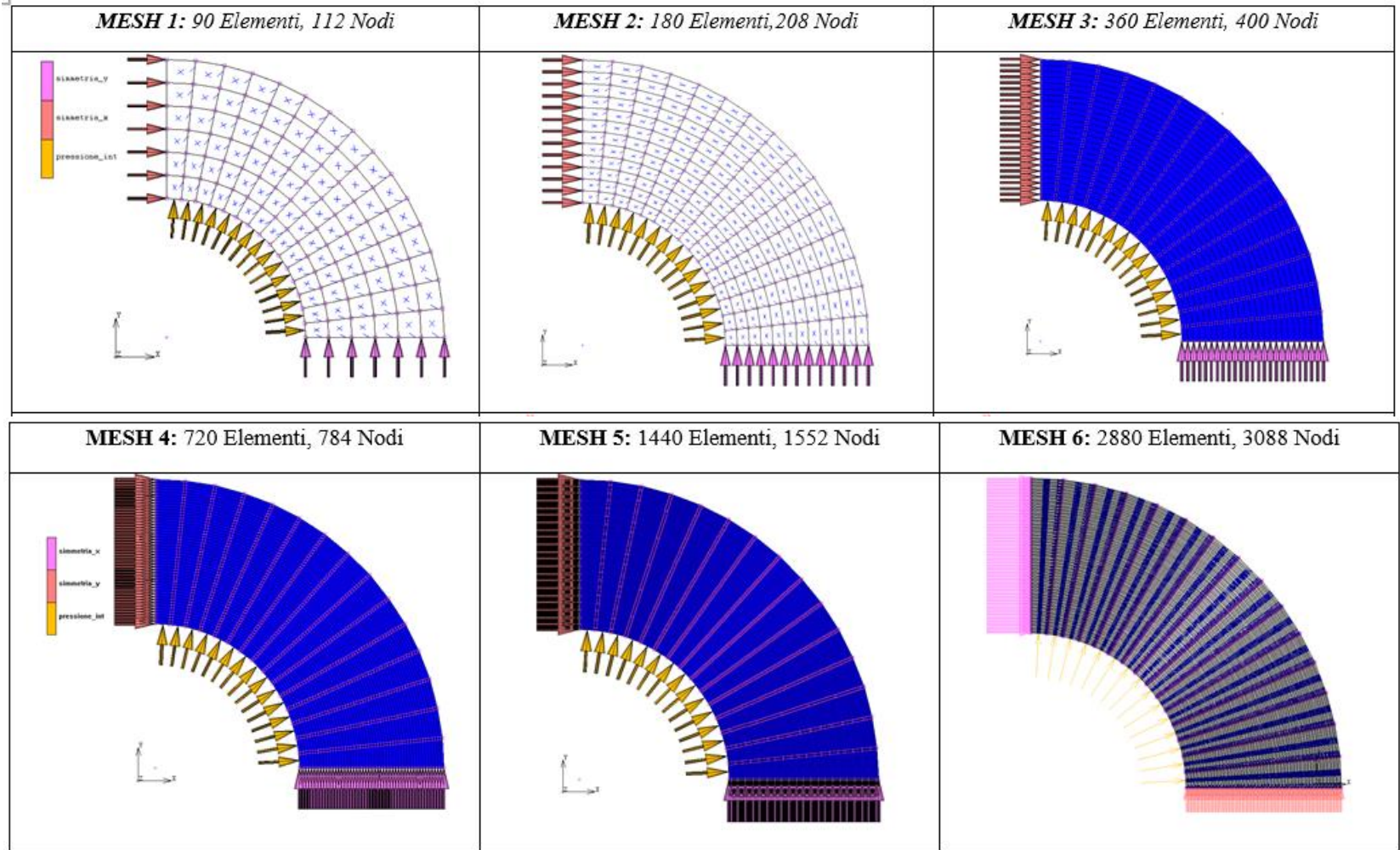
$$\sigma_C \Big|_{r=R_i} = 8.33 \text{ MPa}$$

$$\sigma_r \Big|_{R_{\text{int}}} = -p_{\text{int}}$$

$$\sigma_c \Big|_{R_{\text{int}}} = p_{\text{int}} \frac{R_{\text{est}}^2 + R_{\text{int}}^2}{R_{\text{est}}^2 - R_{\text{int}}^2}$$

# Mesh Convergence

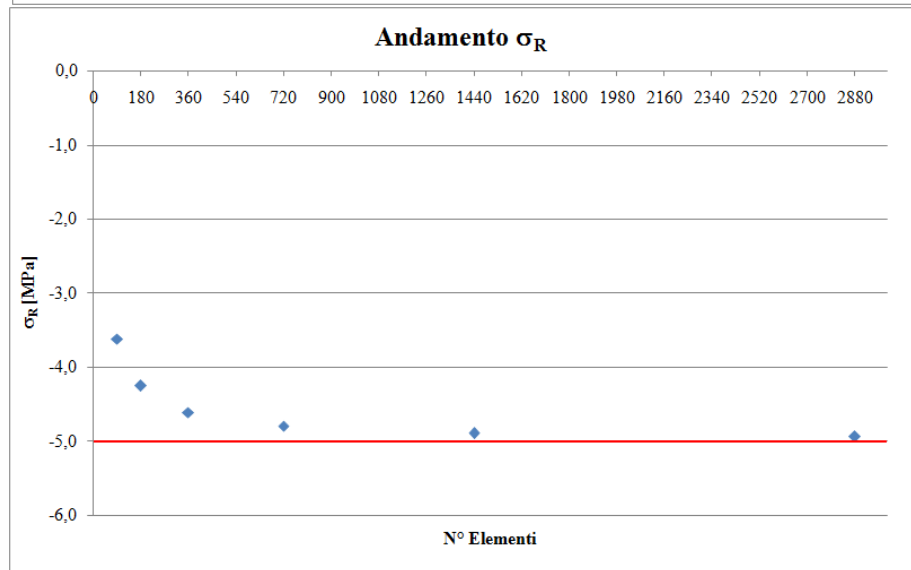
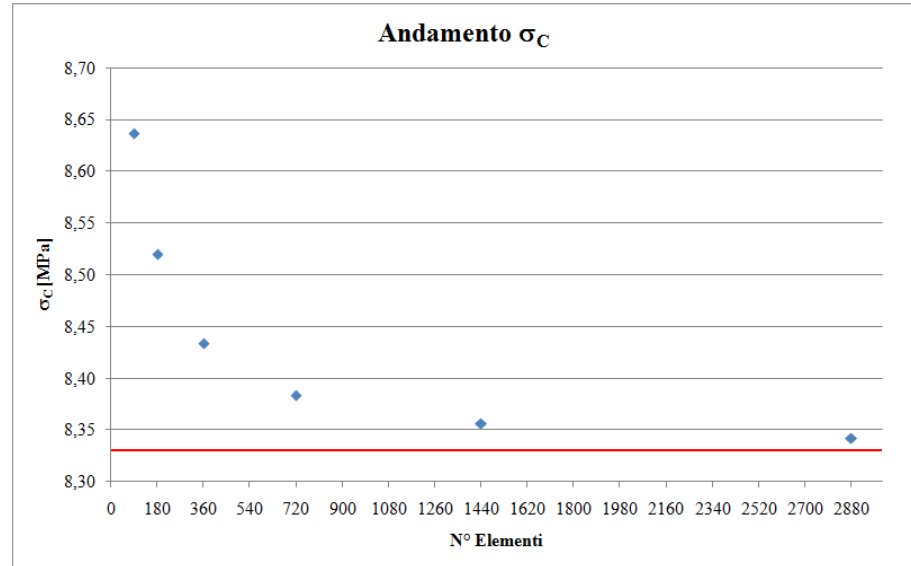
## Critical Aspects: Case B



# Mesh Convergence

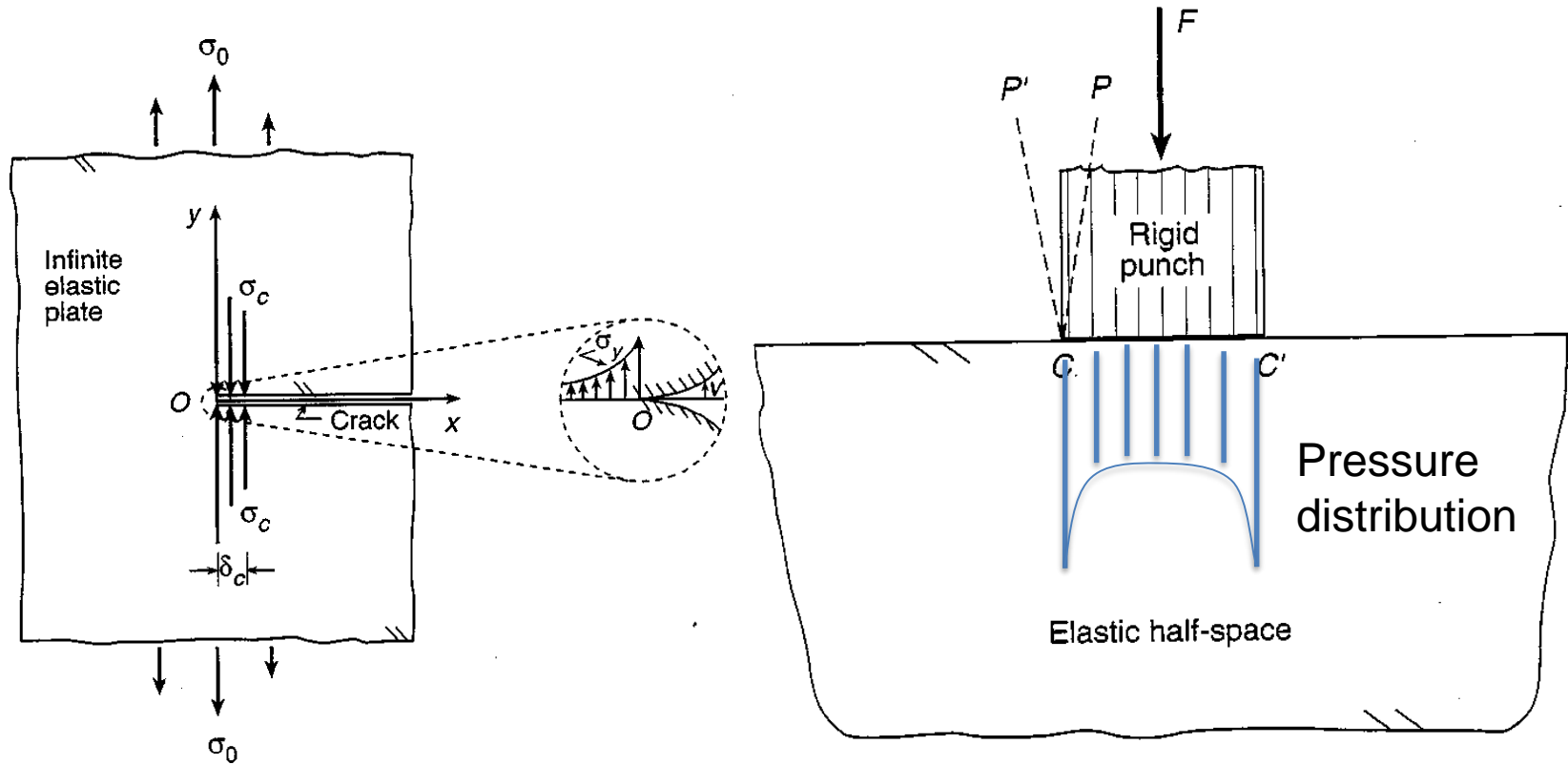
## Critical Aspects: Case B

Asymptotic curve of the FE results with respect to the analytical solution.



# Mesh Convergence

Critical aspects: singularity occurrence



# Agenda

## MSC Marc Mentat: Select entities

- Method & Mode;
- Store;
- Identify set.

## Thin-walled profile in torsion

- Open vs close cross-section;
- Mesh convergence.

## References

# References

## LAB Marc Mentat files saved as:

torsione\_rev01\_nolabile.mud

torsione\_rev01\_nolabile\_open\_vs\_close.mud

torsione\_rev01\_nolabile\_open\_vs\_close\_mesh\_convergence.mud

thin\_walled\_profile\_in\_torsion\_open\_vs\_close.proc

thin\_walled\_profile\_in\_torsion\_open\_vs\_close\_mesh\_convergence.proc

torsional\_stiffness\_evaluation\_paom2019\_v001.ods

## Books and papers:

Strozzi, A. (1998). *Costruzione di Macchine*, Pitagora Editrice, Bologna.

Sinclair, G. B. (2004). Stress singularities in classical elasticity-I: Removal, interpretation, and analysis. *Applied Mechanics Reviews*, 57(4), 251-298.

Sinclair, G. B. (2004). Stress singularities in classical elasticity-II: Asymptotic identification. *Applied Mechanics Reviews*, 57(5), 385-439.