A cost-effective Cold Roll-Forming FE model for industrial applications

Authors: Leonardo Marconi, Timothy Senart, Claudia Cofano

leonardo.marconi@crmgroup.be
timothy.senart@crmgroup.be
claudia.cofano@crmgroup.be

CRM GROUP

For a better future

Index

Introduction

- CRM Group in a nutshell
- Cold Roll-forming process
- Research overview and objectives

CRM Group in a nutshell

CRM GROUP

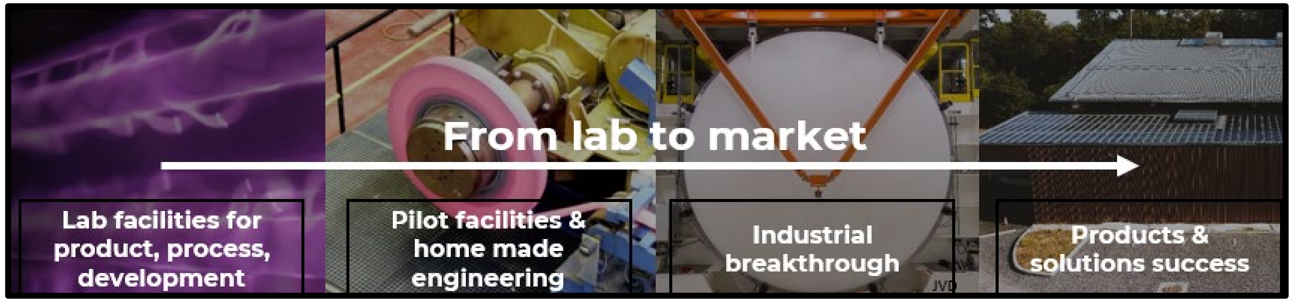
Our Identity:

Founded in 1948 from the merger of independent & private research centres, we focus on *processes*, *products* & *solutions* for the metallurgical industry

Our Mission:

Create value through innovation, transformation and generation of new markets, to empower metals in societal, environmental and economic challenges

Bringing innovation all over the world with more than 265 engineers



Our industrial members

Expertise areas:

- Circular Economy
- Energy Transition
- Construction
- Digitalization
- Advanced Manufacturing

Testing, modeling and optimization of steel structures and manufacturing processes

Cold Roll-forming process

Continuous bending process of a long metal sheet.
The sheet is formed passing through pairs of rotating rolls (stations).
Each station makes an incremental part of the bend.

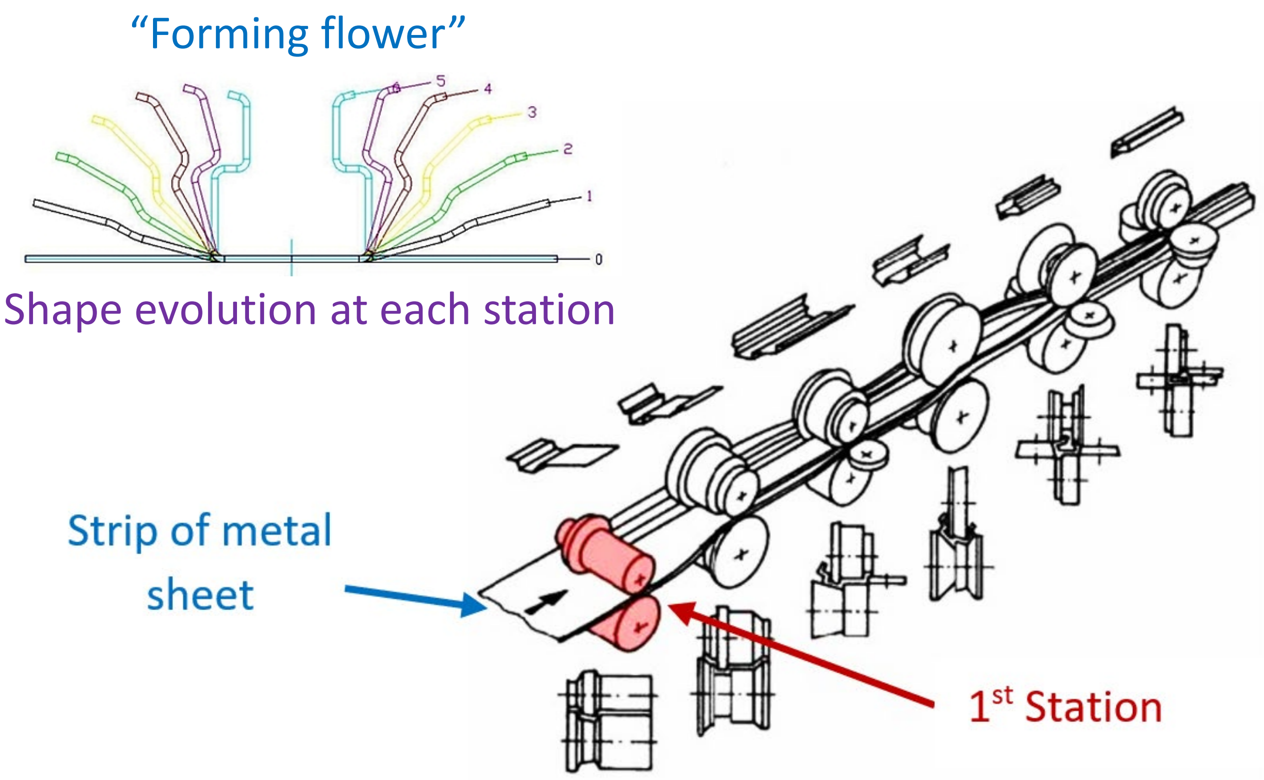


Illustration of a Cold Roll-Forming line, from Urheber GmbH

Strength:

- *High production volume [1]*
- *Capability to form UHSS grades [2]*

Problematics [3]:

- *Geometrical imperfections*
- *Unbalanced springback*

Research goal and methodology

Aim:

Developing a cost-effective methodology to investigate cold roll-forming processes in LS-DYNA

Research phases :

Test campaign

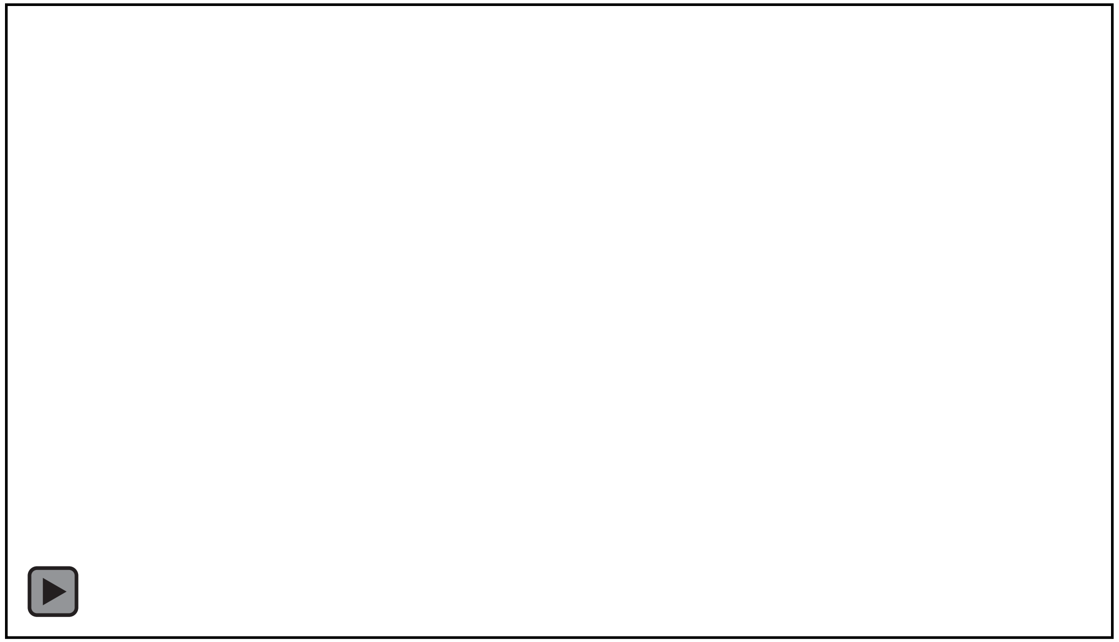
To validate:

- Process design parameter
- Model assumptions

Numerical model creation

Goals:

- Accuracy
- Pre-processing ease
- Computational efficiency



Cold roll forming FE model on LS Dyna

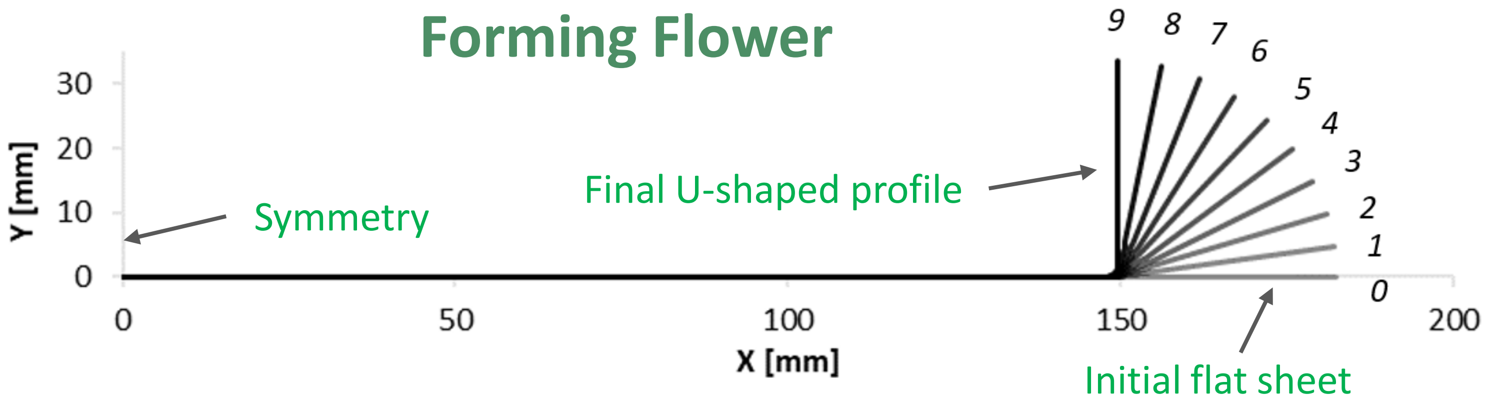
Experimental campaign

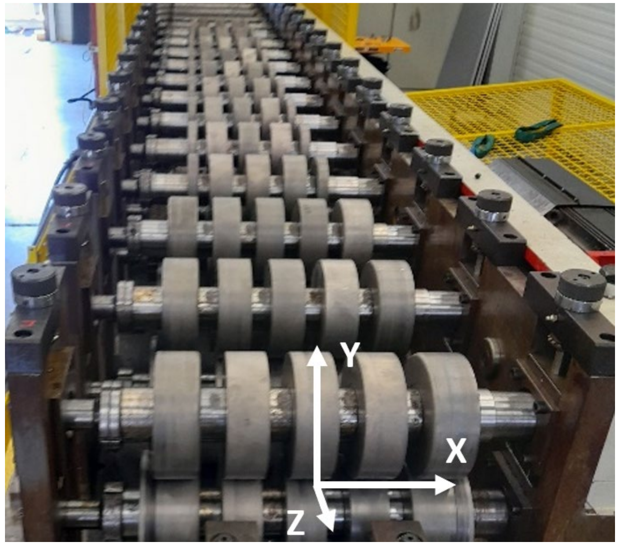
- Experiment set-up
- Outputs
- Observations

Experiment set-up

Pilot cold roll-forming line:

- Station: 9 (equally spaced 250mm)
- Blank speed: 4.2 m/min





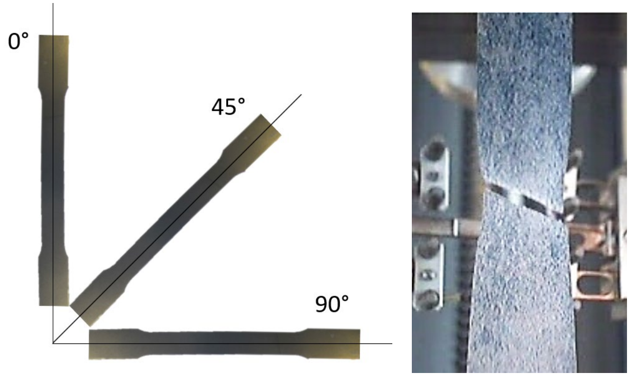
Cold roll-forming line at CRM Group

Specimen:

- Dimensions: 0.63mm thick, 2000mm long, 360mm wide
- Material: S350GD grade (characterized by tensile tests EN ISO 6892)

Tools:

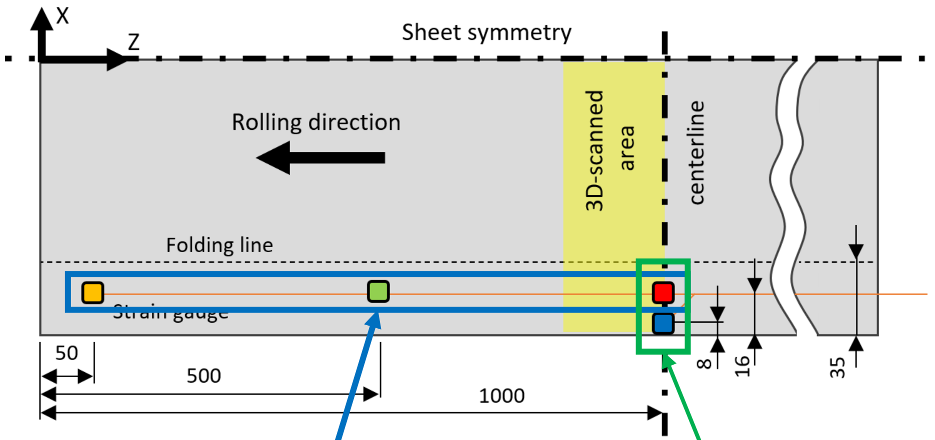
- 3D scan (→ Cross section)
- Strain gauges (→ Longitudinal strain)



Material characterization

Experimental output – Longitudinal strain

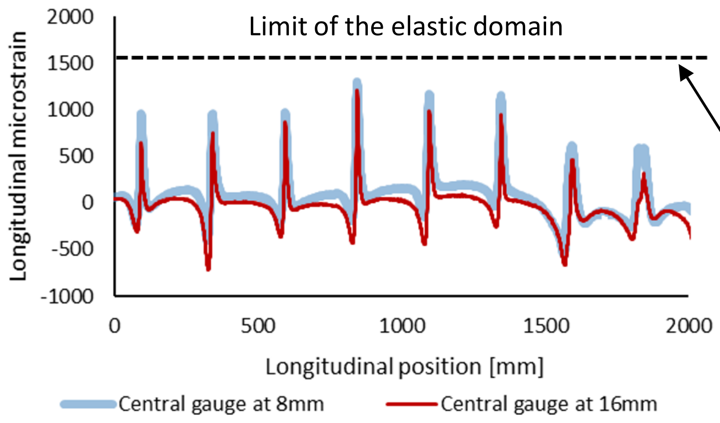
Gauges disposition on the specimen



Central gauges for correlation

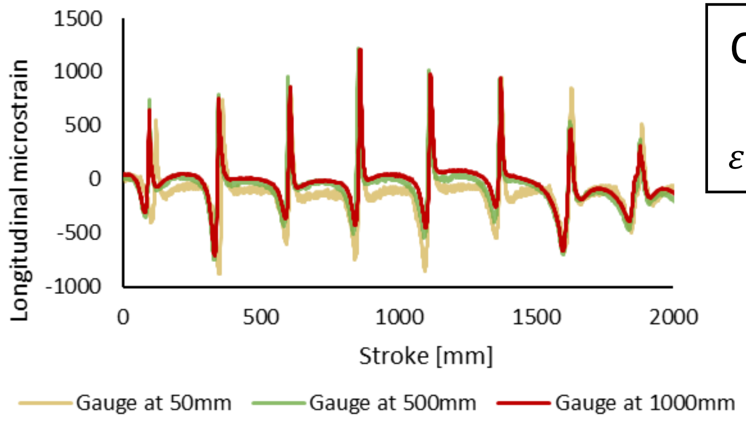
Longitudinal gauges for verification

Central gauges for correlation



Design rule satisfied

Longitudinal gauges for verification

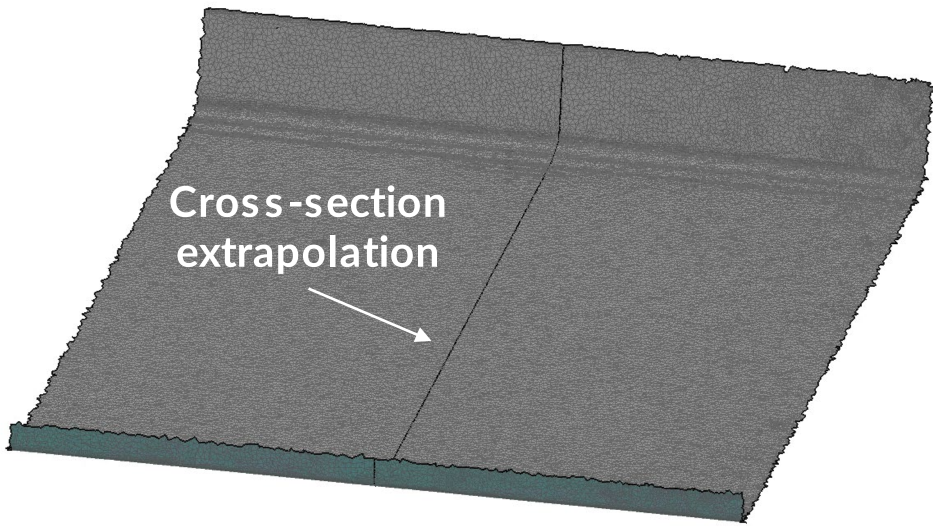


Central gauges verified

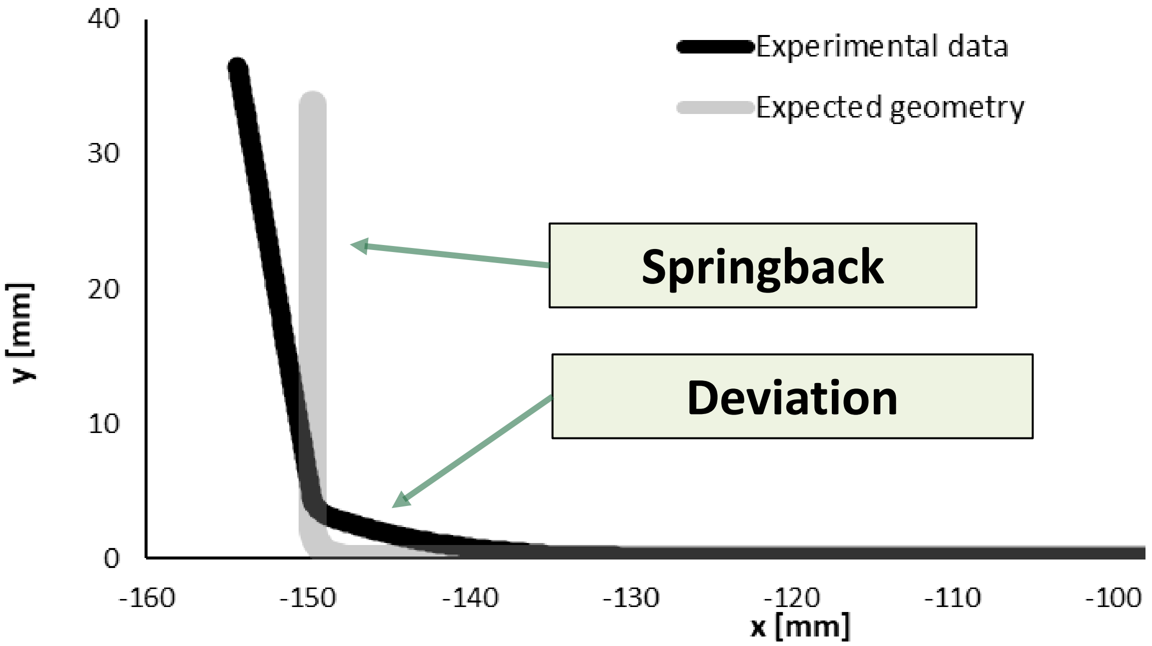
$\varepsilon_{50} \neq \varepsilon_{500} = \varepsilon_{1000}$

Experimental outputs – Cross-section

3D scanned final profile



3D scanned final profile



Final cross-section of the central section

Campaign conclusion

Experimental campaign outcomes:

1) Results for correlation

- Longitudinal strain
- Final cross section

2) Observations

- Low roll eccentricity and displacement
- Blank-line misalignment controlled

3) Open question

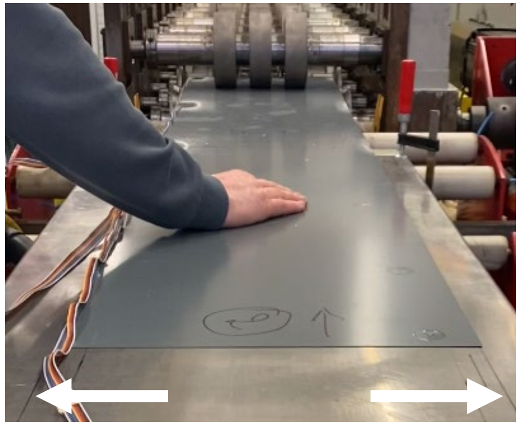
- Cross section deviation

Observations:

Low eccentricity and displacement

Rolls *displacement* < 0.25mm
(of which 0.12mm of *eccentricity)*

No feeding misallignment



Numerical model

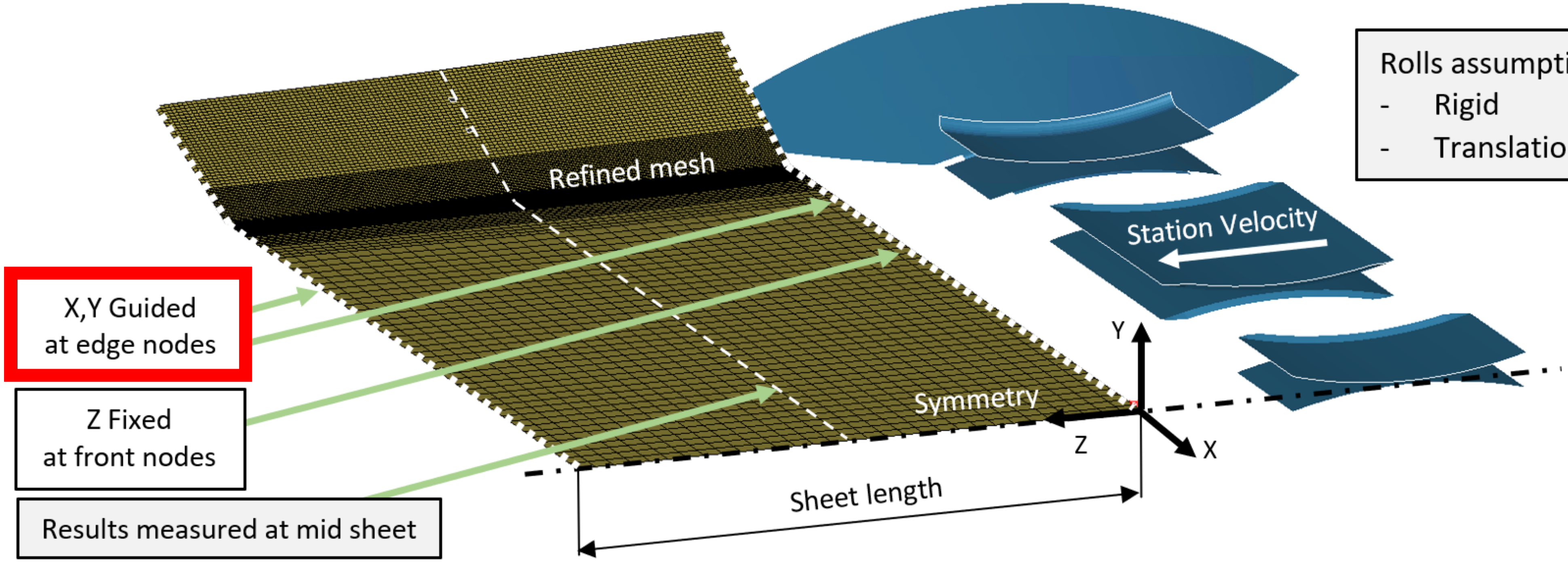
- FE Methodology
- Guiding script
- Sensitivity and Calibration
- Results

Non-linear Finite Element Model

- **Method** → Non-linear static implicit FEM
- **Material** → Isotropic elasto-plastic law (Type 24)
- **Section** → Fully integrated shell elements (Elform 16)
- **Contact** → FORMING_SURFACE_TO_SURFACE_MORTAR
- **MPP domain** → dec { region { parts 10 sx 1.e9 } sx 1.e9 }

Inputs:

1) Sheet properties
2) Forming line geometry
3) Roll forming flower



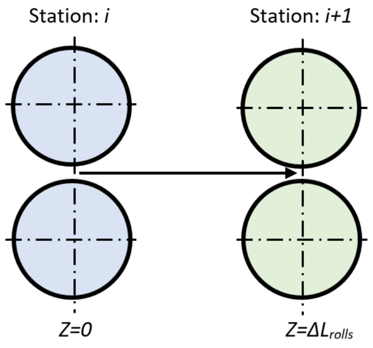
Rolls assumptions:
- Rigid
- Translation only

Guiding method

Guiding [4-5] applied to node "***N***" between stations "***i***" and "***i+1***":

- $$X_{i_{(Z,N)}} = X_{i_{(N)}} + \left[X_{i+1_{(N)}} - X_{i_{(N)}} \right] \sin\left(\frac{\pi}{2} \left(\frac{Z}{\Delta L_{rolls}} \right)^{n_{EXP}} \right)$$
- $$Y_{i_{(Z,N)}} = Y_{i_{(N)}} + \left[Y_{i+1_{(N)}} - Y_{i_{(N)}} \right] \sin\left(\frac{\pi}{2} \left(\frac{Z}{\Delta L_{rolls}} \right)^{n_{EXP}} \right)$$

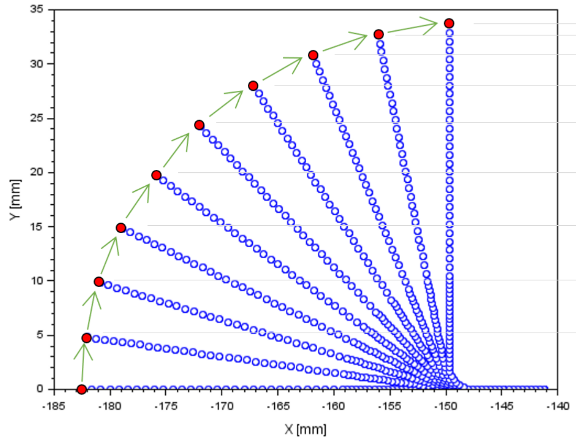
Script to automatically create equations and boundaries



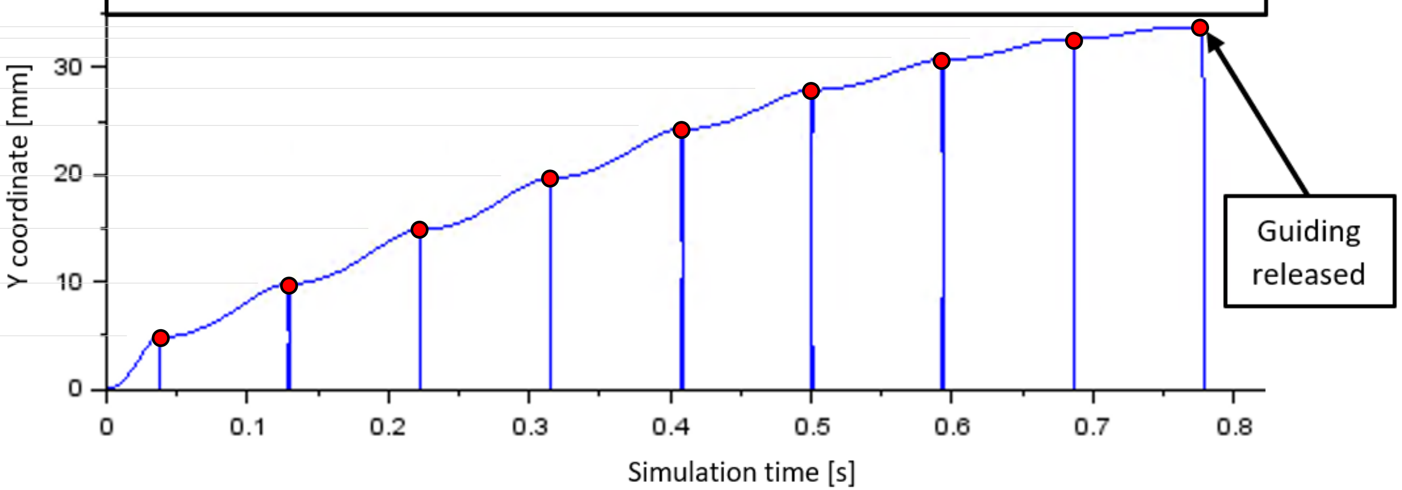
Local "Z" reference system

$\boldsymbol{X_{i_{(N)}}}$, $\boldsymbol{Y_{i_{(N)}}}$ for each "***N***" and "***i***" are input through the "meshed forming flower":

Discretized forming flower



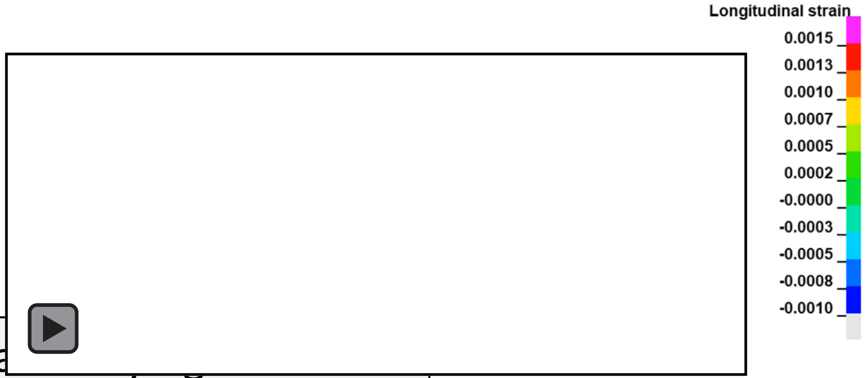
Forming flower – Last node highlighted



Y interpolation path (Last node for n_{EXP} =2)

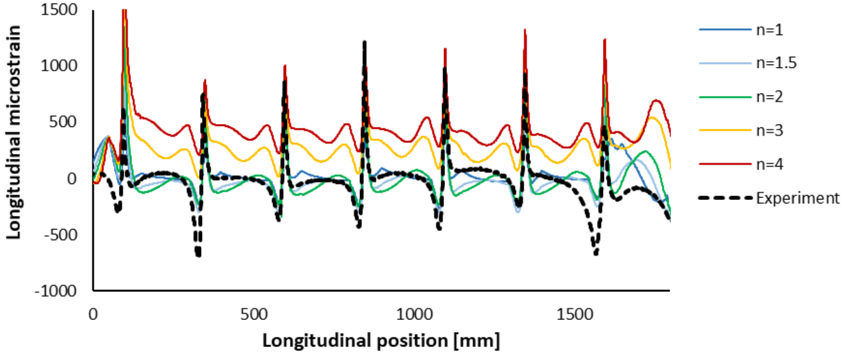
Sensitivity analysis

SHEET LENGTH: 100 mm



Stra

High sensitivity on guiding shape

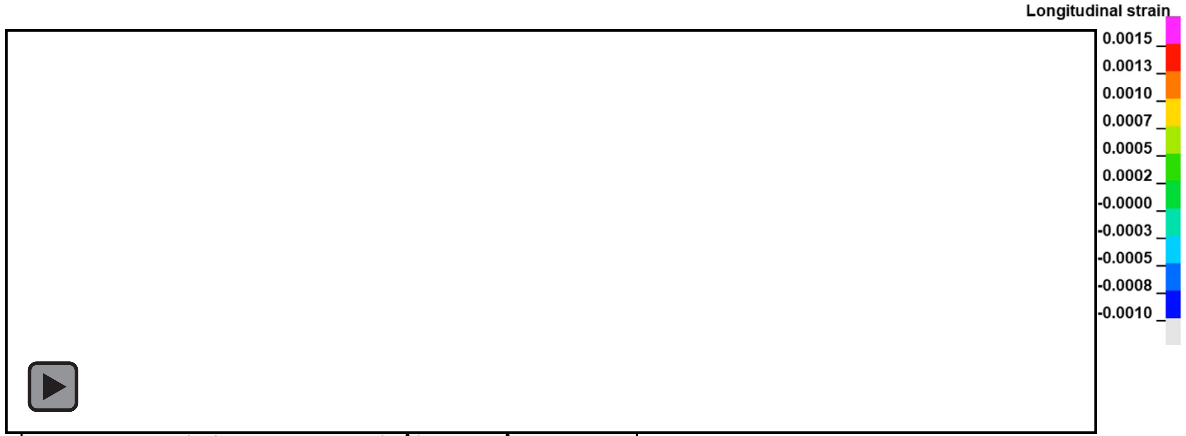


Longitudinal strain fringe (L=100mm, Analysis time: 15h, 18 CPU)

sensitivity

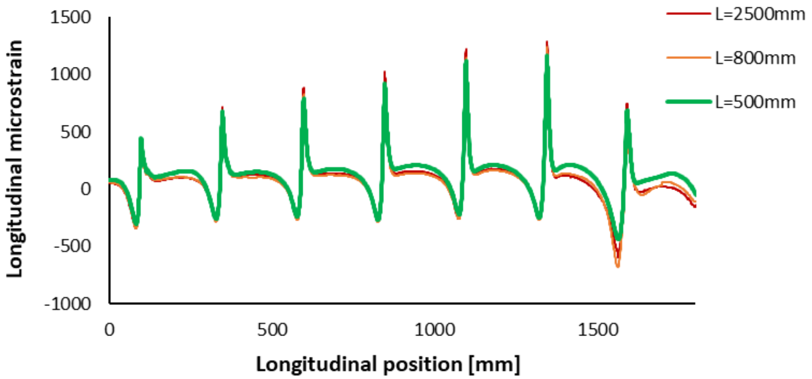
Guiding shape

SHEET LENGTH: 500 mm



Insensitive to guiding shape

Sheet length converged

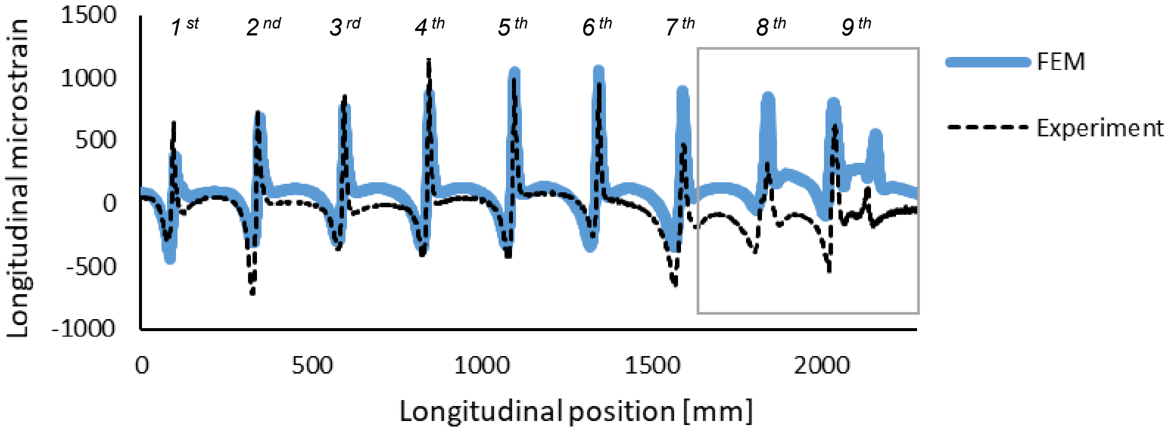


Longitudinal strain fringe (L=500mm, Analysis time: 24h, 18 CPU)
(n=2)

Sheet length sensitivity

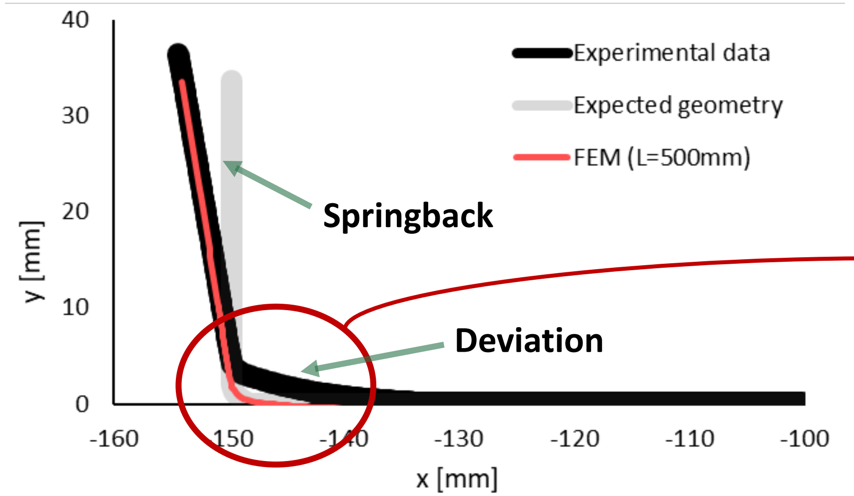
Correlation status

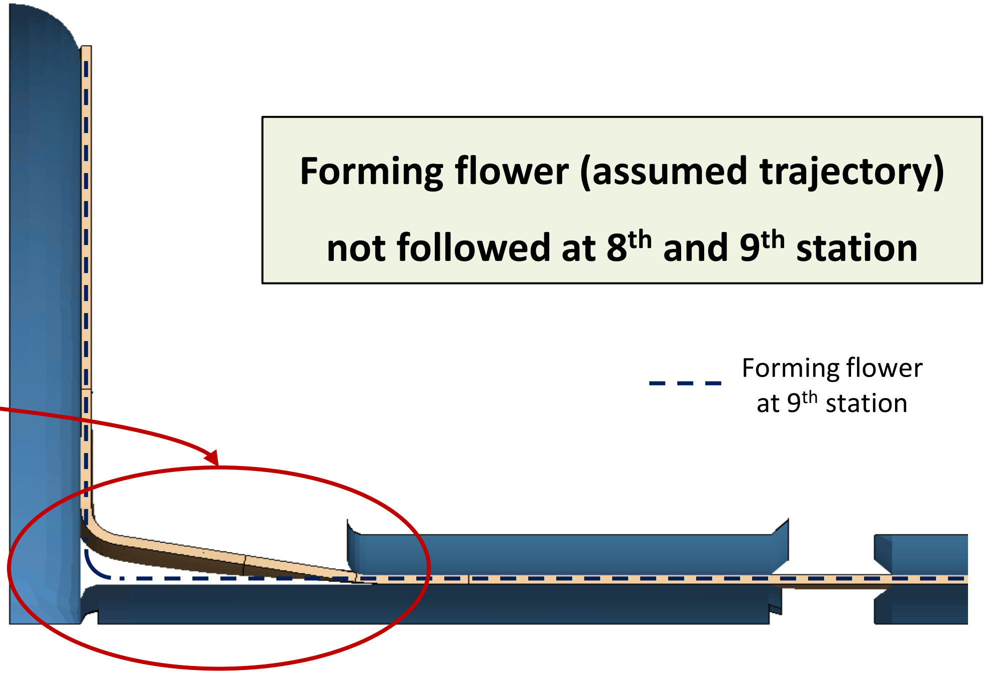
1) Longitudinal strain



- Accurate correlation
- Deviation after 7th station

2) Final cross-section

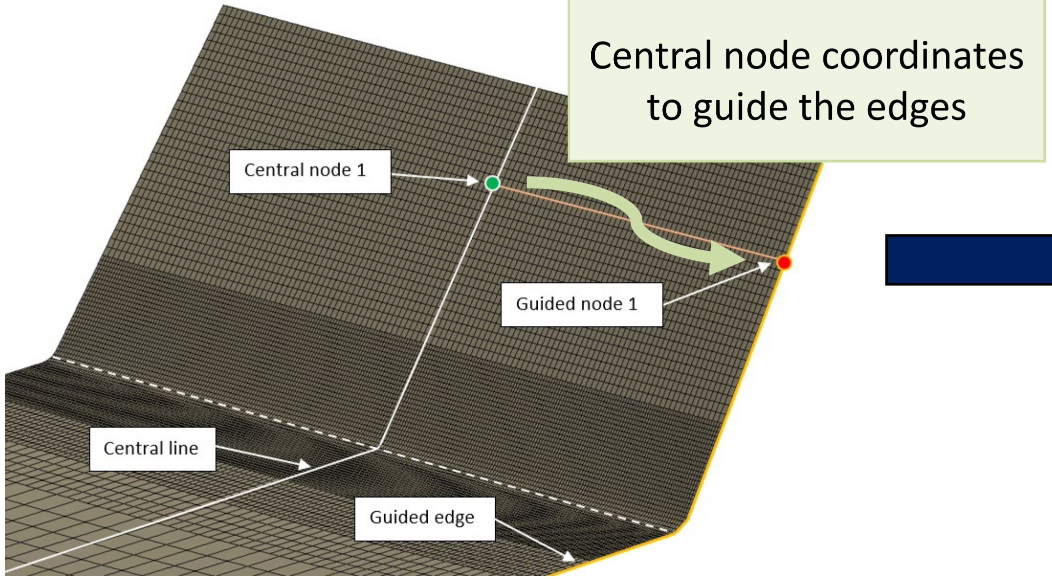




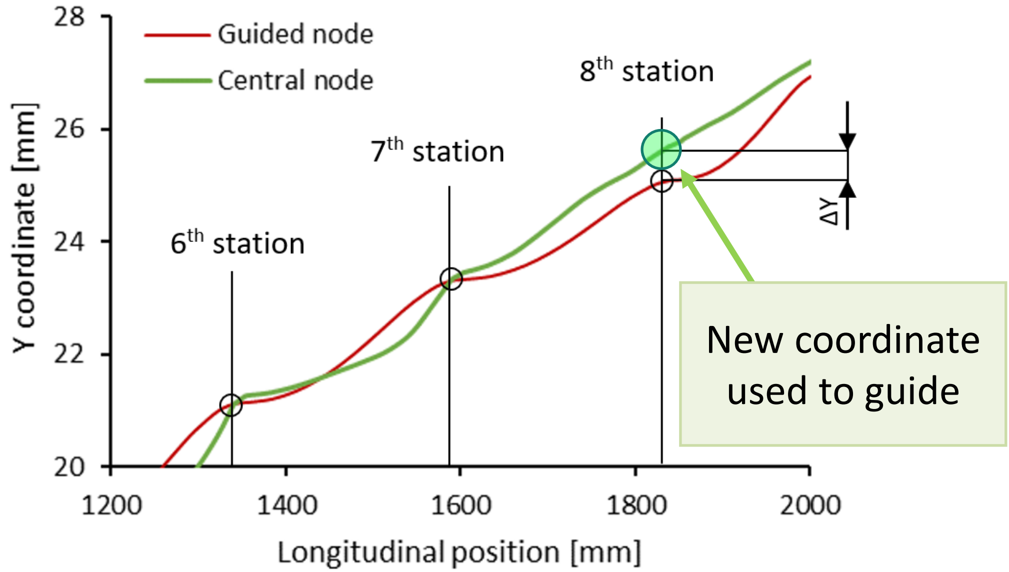
Forming flower (assumed trajectory) not followed at 8th and 9th station

Calibration Phase

Sheet schematics

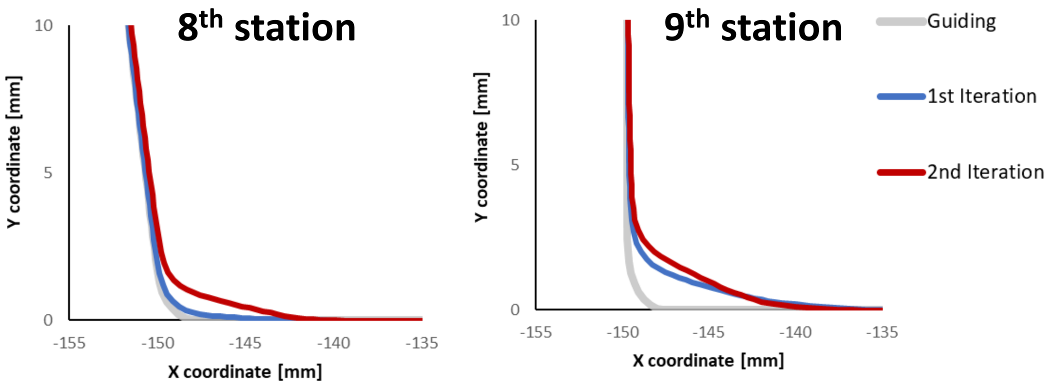


Y trajectory of guided and central node

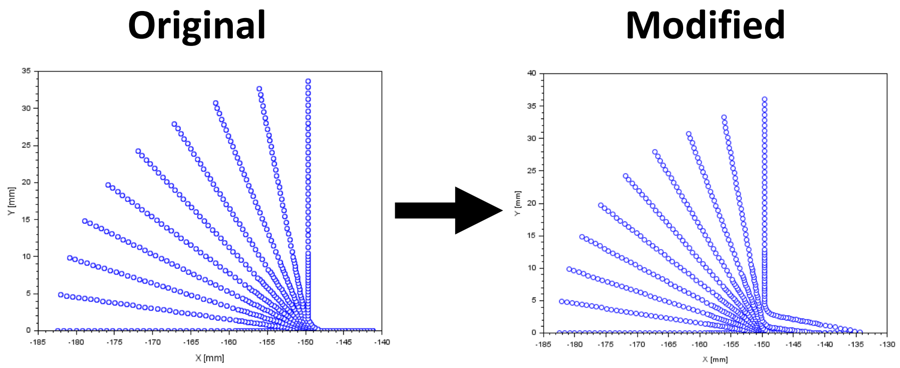


Iterative Procedure

Forming flower evolution for 2 iterations

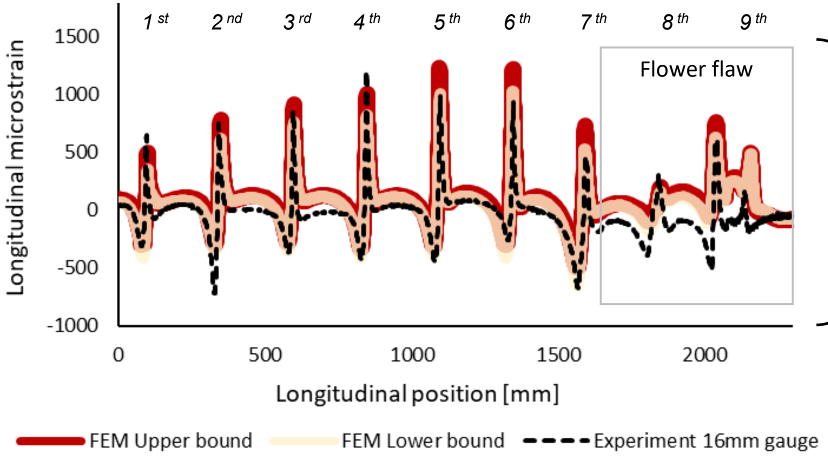


Input modification

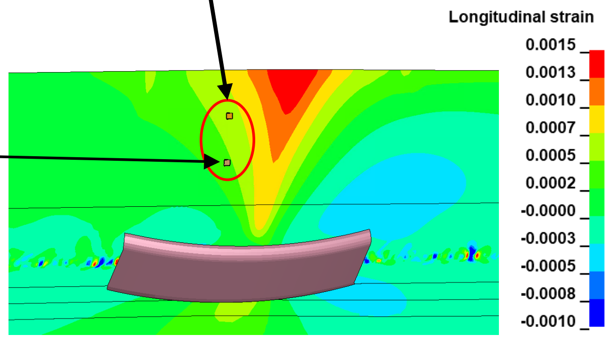


Results

1) Longitudinal strain

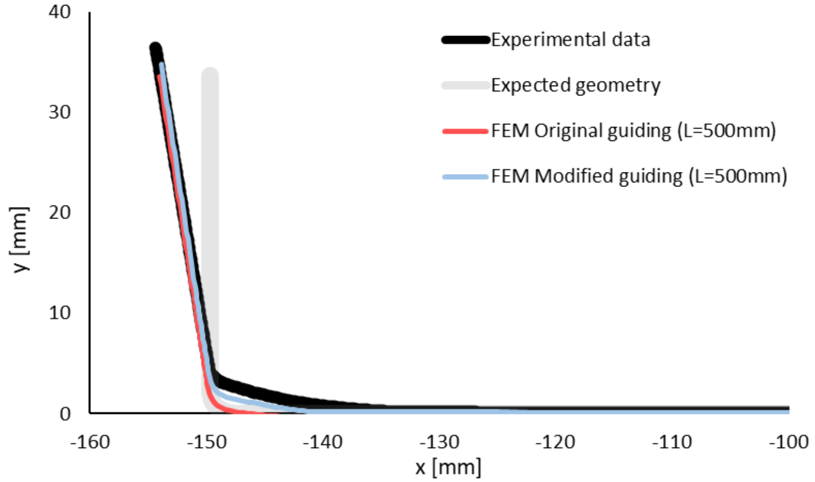


Strain field on the flange
Correlation at 2 points

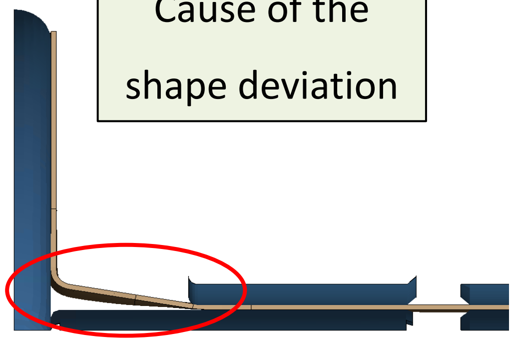


- **Accurate correlation:**
  - Prediction of strain gradient
  - Better trend after 7th station
- **Robust results**
- **Uncertainty range:**
  - Material properties
  - Gauge misalignment (±2.5°)

2) Final cross-section



Cause of the shape deviation



- **Prediction of spring back**
- **Simulation of the deviation**
- **Correction of forming flower**

…

Conclusions

- Conclusions
- Future works

Conclusions

- **Project aim:**

To create a numerical methodology able to give *fast* and *accurate* data about the cold roll-forming process.

Forming process design → Numerical model creation→ Process check

Pros	Cons
1) Results accuracy & robustness	**1) Roll forming line stiffness**
○ Major outputs validated	○ No effects of roll-forming line flexibility
○ Possibility to check the forming flower	○ ***Future work***
○ Small uncertainty range	
2) Cost-Effectiveness	**2) Different physics of the rolls**
○ *Analysis time < 24h* (18 CPU, Intel® Xeon® W-2195 2.30GHz)	○ No info about the rolls torque required
○ Small portion of the blank modelled	○ No sensitivity about friction coefficient
○ Highly automatized pre-processing	
3) Easy to interface with other models	
○ LS-DYNA makes it easy VS. dedicated software	
○ ***Future work & final aim of this investigation***	

Future works

1) Validation of new profiles

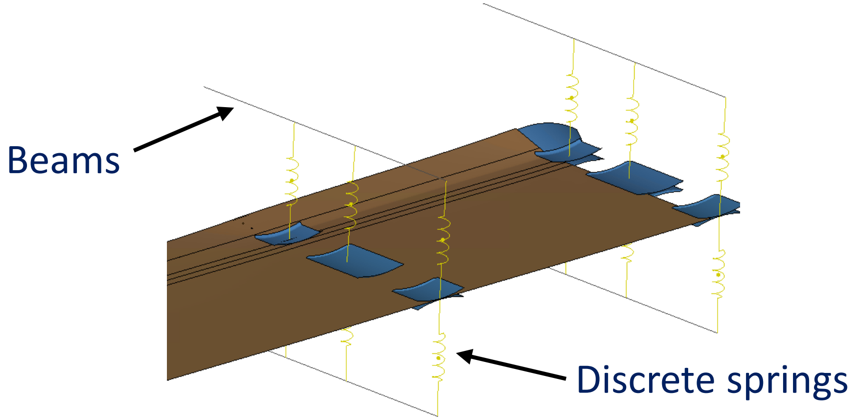
2) "Semi-rigid" roll-forming line

To account for roll-forming line flexibility

Stiffness of the line:

- Axis modelled through beam elements
- Rolls' stiffness modelled through springs

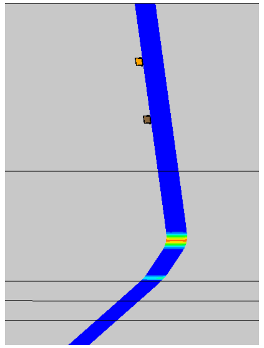
Semi-rigid line on LS-DYNA



3) Study effects of manufacturing over product performances

Mapping stress/strain state from manufacturing.

Convenient on LS-DYNA



Extraction of outputs at mid-sheet and mapping

Thank you

www.crmgroup.be

leonardo.marconi@crmgroup.be
timothy.senart@crmgroup.be
claudia.cofano@crmgroup.be

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Literature

[1] Liu, Huamin, Zhiqing Liu, and Zhongping Zou. "FEM Simulation of Cold Roll Forming in the Car's Anti-Collision Beam." Journal of Computational and Theoretical Nanoscience 9.9 (2012): 1472-1476.

[2] Tsang, Kwun Sing, et al. "Industrial validation of strain in cold roll forming of UHSS." Procedia Manufacturing 15 (2018): 788-795.

[3] Watari, Hisaki, and Hiroshi Ona. "Characteristic features of shape defects occurring in the cold roll forming of pre-notched products." Journal of Materials Processing Technology 80 (1998): 225-231.

[4] Kiuchi M, Koudabashi T. “Automated design system of optimal roll profiles for cold roll forming.” Proceedings of the third international conference on rotary metalworking processes, Kyoto, Japan (1984): 423–36.

[5] G.T Halmos: “Roll forming handbook”, CRC Press, 2005

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