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WARPING SECTION ANALYSIS BY NUMERICAL MODELLING AND VOLUME MEASUREMENTS TECHNIQUES

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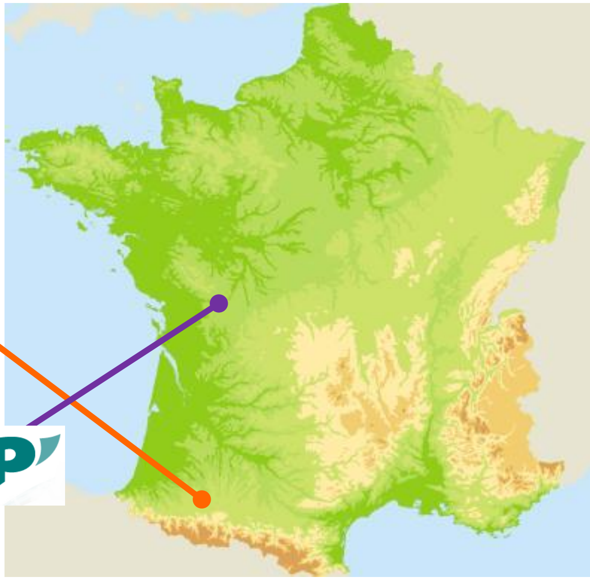
OUTLINE

- Problematics
- Analytical theories
- Numerical approach
- Experimental visualization
- Conclusion & perspectives

CONTEXT

- PhD work
- LGP/ENIT, Tarbes, France
- P' Institute, Poitiers, France

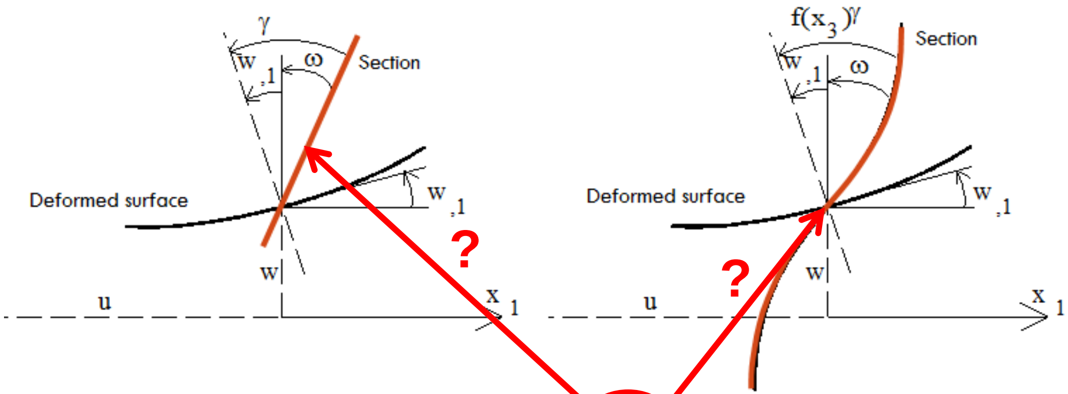


Subject

- Composite mechanical behavior analysis
- Transverse shear & warping section
- X-ray tomography measurements
- Digital Volume Correlation (DVC)

OBJECTIVES

- Warping section in composite : 3D study
  - Validity of analytical theories ?
  - Homogeneous thickness distribution ?



$$\mathbf{u} \begin{cases} u_i = u_i^0 - x_3 u_{3,i}^0 + f(x_3)\gamma_{i3}^0, & i = 1,2, \\ u_3 = u_3^0, \end{cases}$$

PROBLEMATICS

- **Comparison of transverse shear functions $f(x_3)$?**
  - Polynomial, cubic, sinus, exponential, etc…?
  - Differents validation cases
  - Measurements accuracy

PROBLEMATICS

- **Numerical modelling of and visualization of warping ?**
  - Boundary conditions
  - Influence of bending supports

PROBLEMATICS

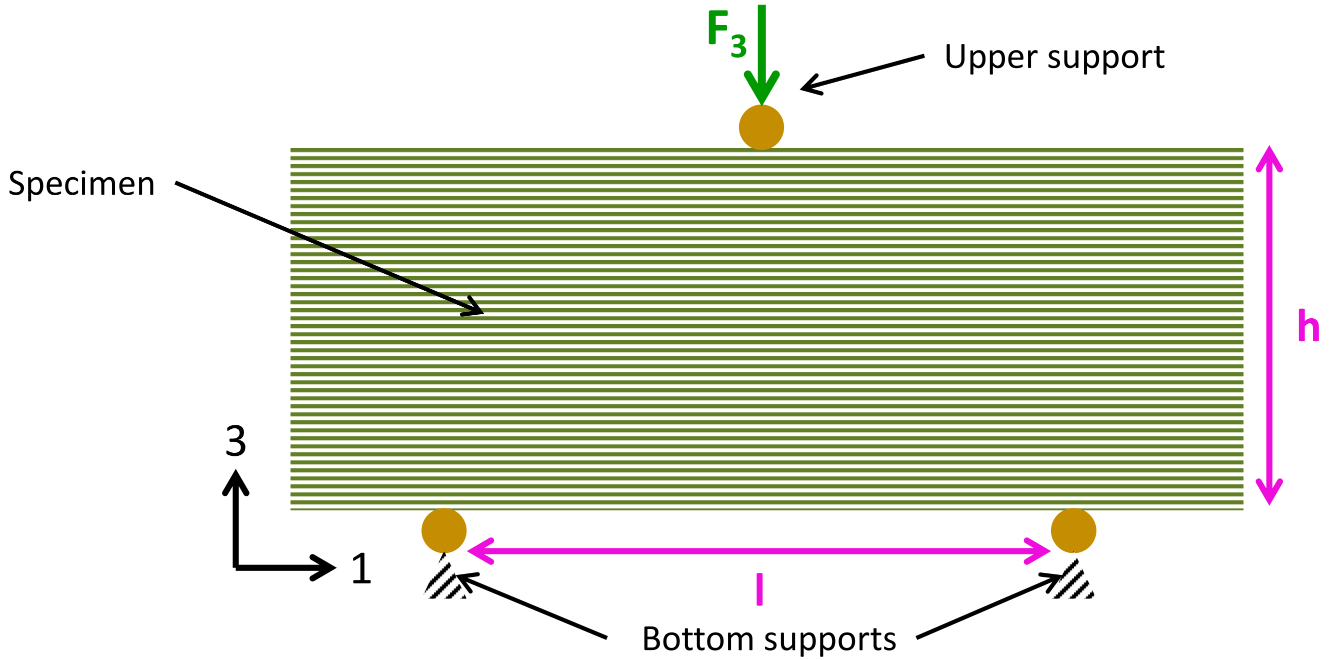
- **X-µCT & composite materials ?**
    - Internal natural constrast
    - Interest of markers
    - Specimen volume & spatial resolution

PROBLEMATICS

- **Digital volume correlation & composite materials ?**
  - Markers influence on specimen behavior
  - In-situ loading system development
  - Measurements accuracy

Three-Point Bending Case

- Analytical solve : (Dufort, 2000)



TRANSVERSE SHEAR FUNCTIONS

- Use of 6 kind of theories $f(x_3)$

$$f(x_3) = 0 \quad Kirchoff - Love$$ → No transverse shear

$$f(x_3) = x_3 \quad Reissner - Mindlin$$ → Linear

$$f(x_3) = x_3\left(1 - \frac{4x_3^2}{3h^2}\right) \quad Reddy$$ → Cubic

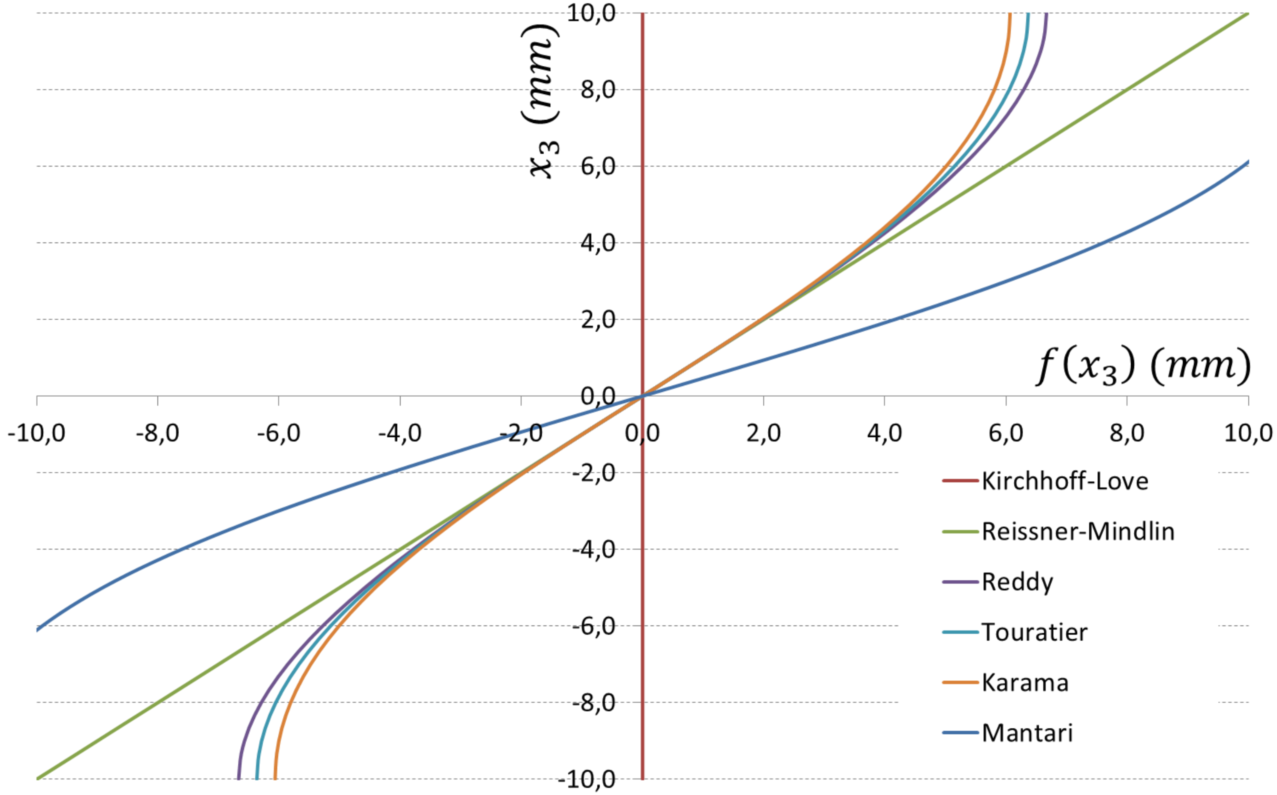
$$f(x_3) = \frac{h}{\pi} sin\left(\frac{\pi x_3}{h}\right) \quad Touratier$$ → Sinus

$$f(x_3) = x_3 e^{-2(x_3/h)^2} \quad Karama$$ → Exponential

$$f(x_3) = sin\left(\frac{\pi x_3}{h}\right) e^{\frac{1}{2}cos\left(\frac{\pi x_3}{h}\right)} + \frac{\pi}{2h}x_3 \quad Mantari$$ → Sinus/Exponential/Cosinus

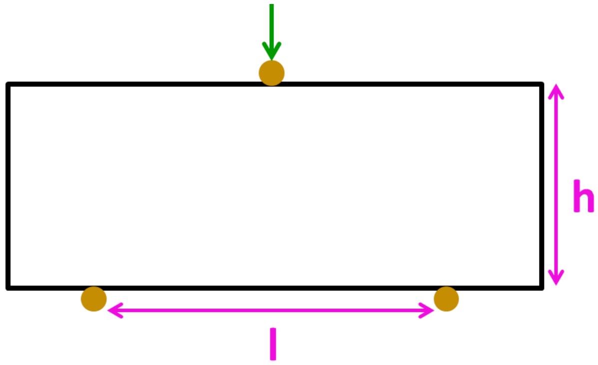
Transverse shear functions

- Use of 6 kind of theories $f(x_3)$



TRANSVERSE SHEAR FUNCTIONS

- Three cases of structures



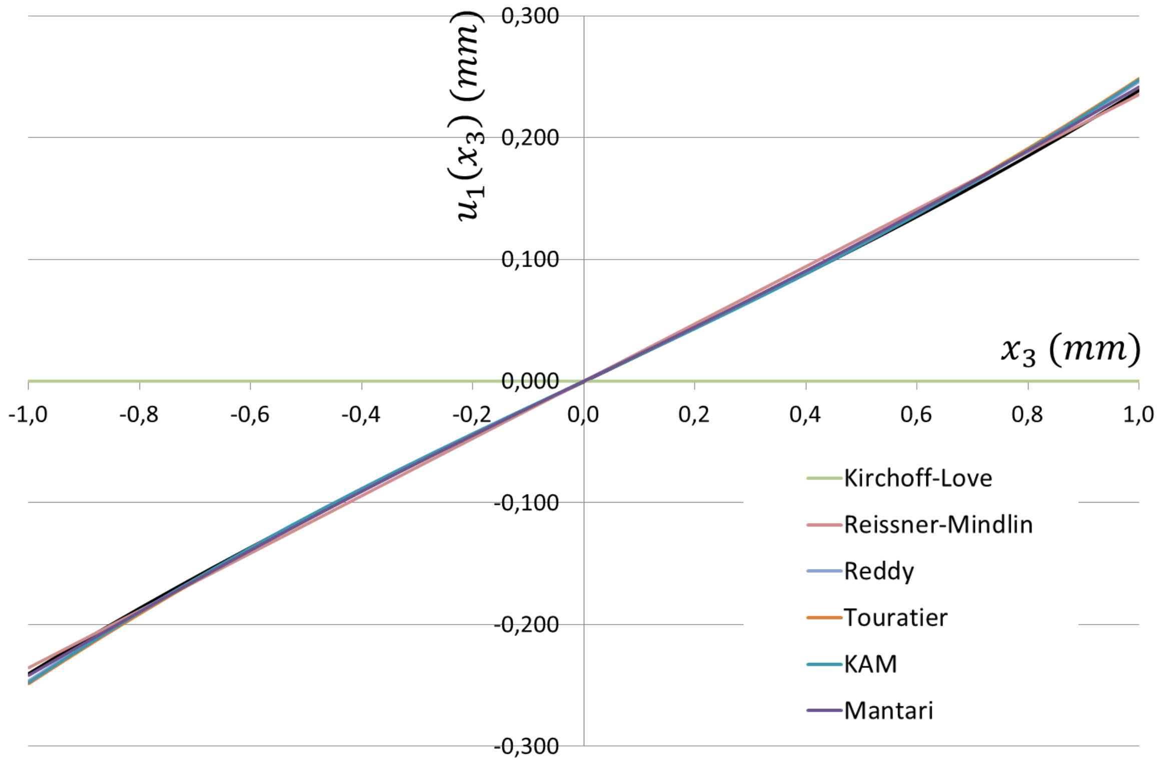
l/h = 12.5

l = 25mm

h = 2mm

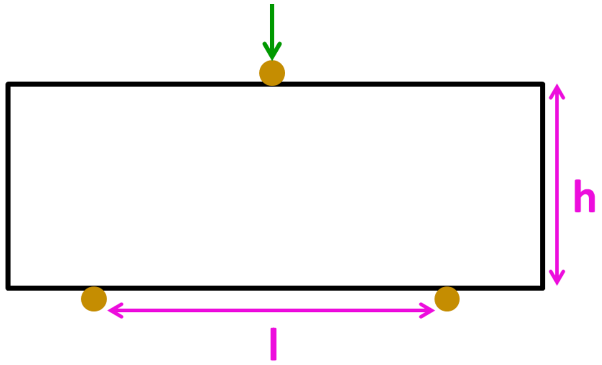
E_{11} = 140 GPa

G_{13} = 3.5 GPa



TRANSVERSE SHEAR FUNCTIONS

- Three cases of structures



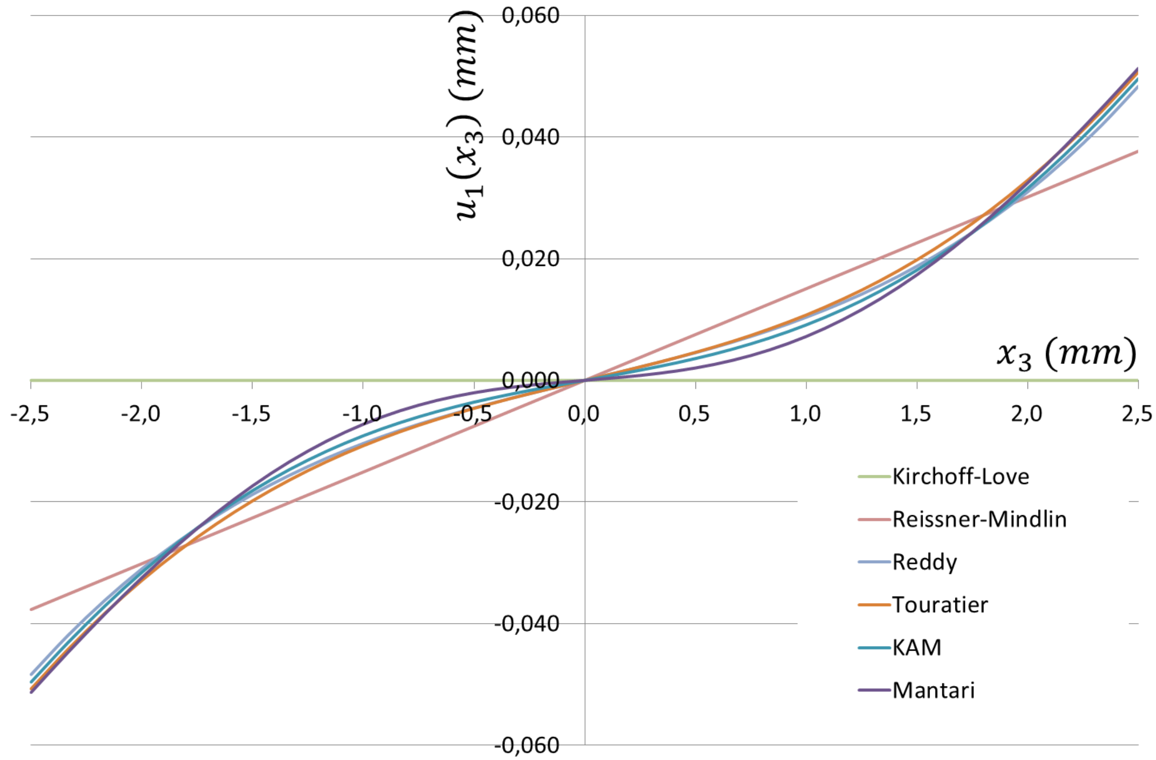
l/h = 5

l = 25mm

h = 5mm

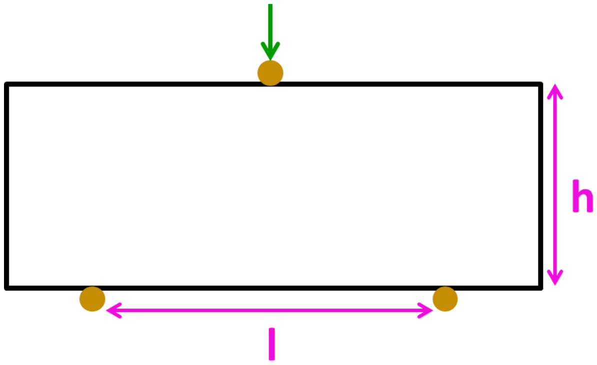
E_{11} = 140 GPa

G_{13} = 3.5 GPa



TRANSVERSE SHEAR FUNCTIONS

- Three cases of structures



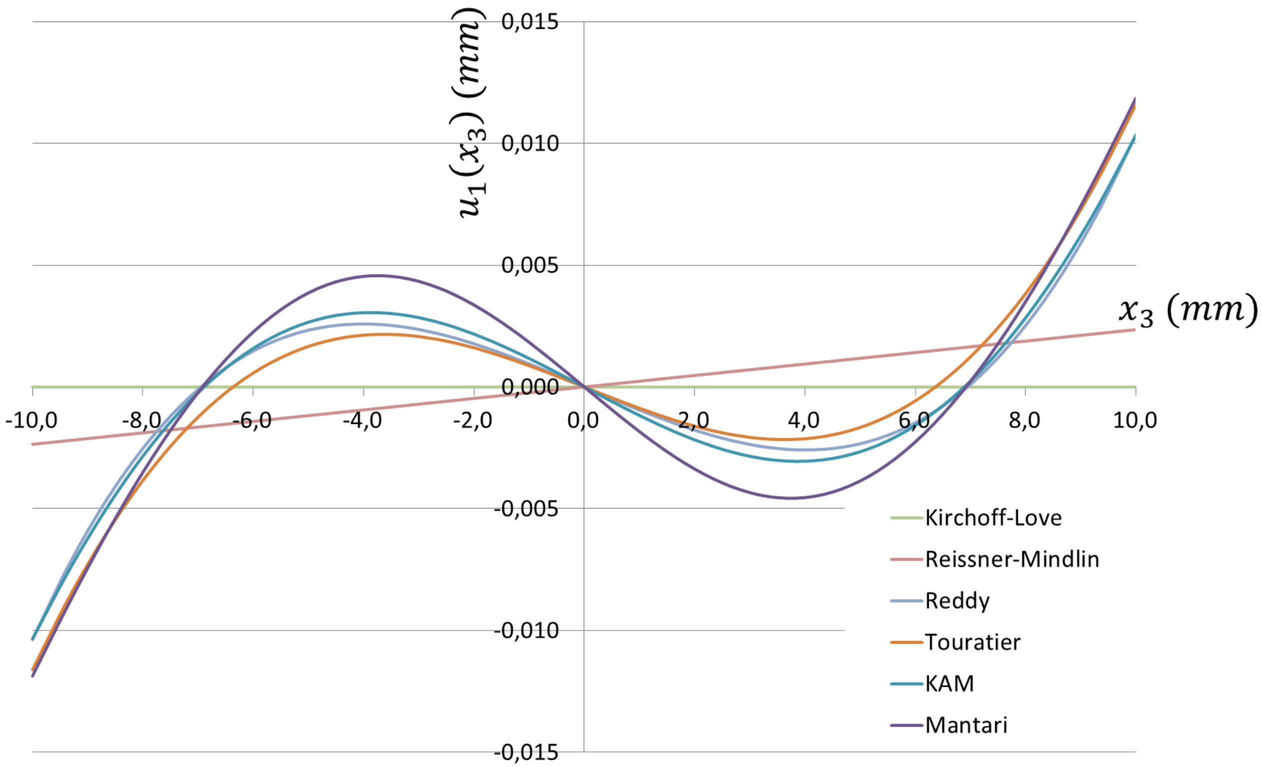
l/h = 1.25

l = 25mm

h = 20mm

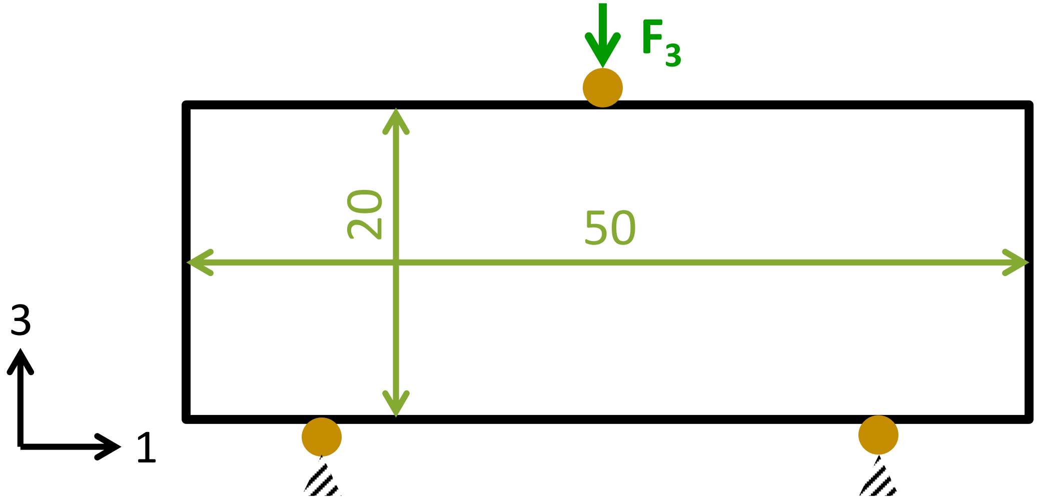
E_{11} = 140 GPa

G_{13} = 3.5 GPa



Three-Points Bending Testing

- Transverse shear effects visualization
- Simple specimen geometry



NUMERICAL MODELLING

- 2D plane stress modelling

l/h = 1.25

l = 25mm

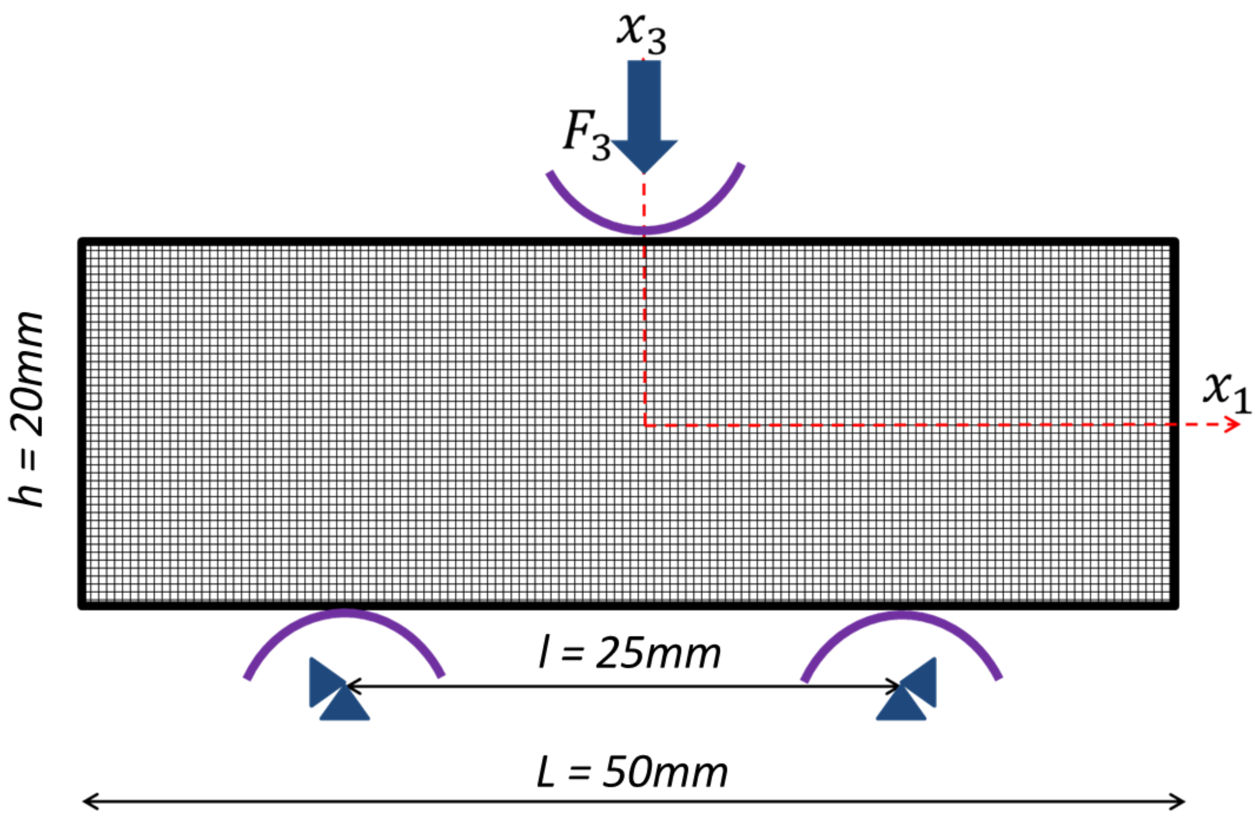
h = 20mm

E_{11} = 140 GPa

G_{13} = 3.5 Gpa

4000 Elements CPS8R

Abaqus CAE



NUMERICAL MODELLING

- FEM : Reference results

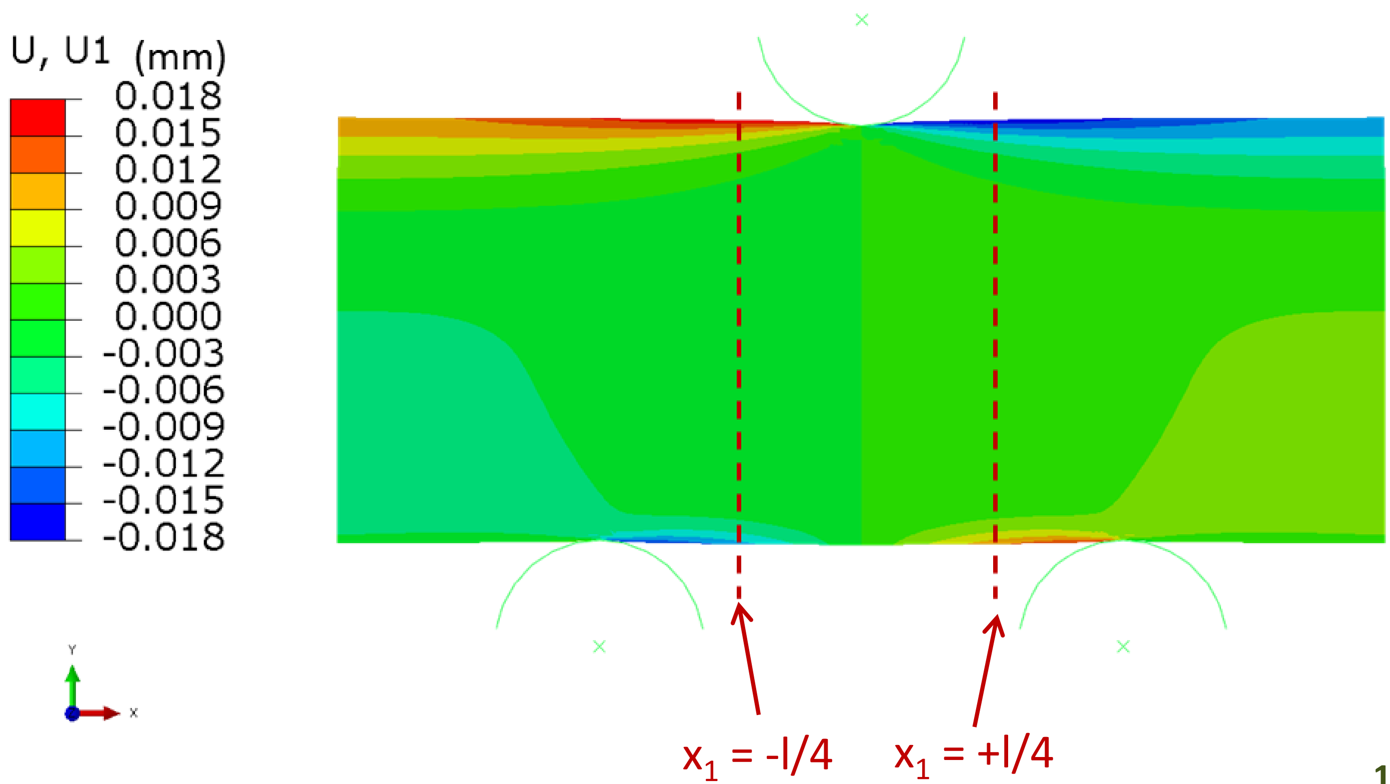
l/h = 1.25

l = 25mm

h = 20mm

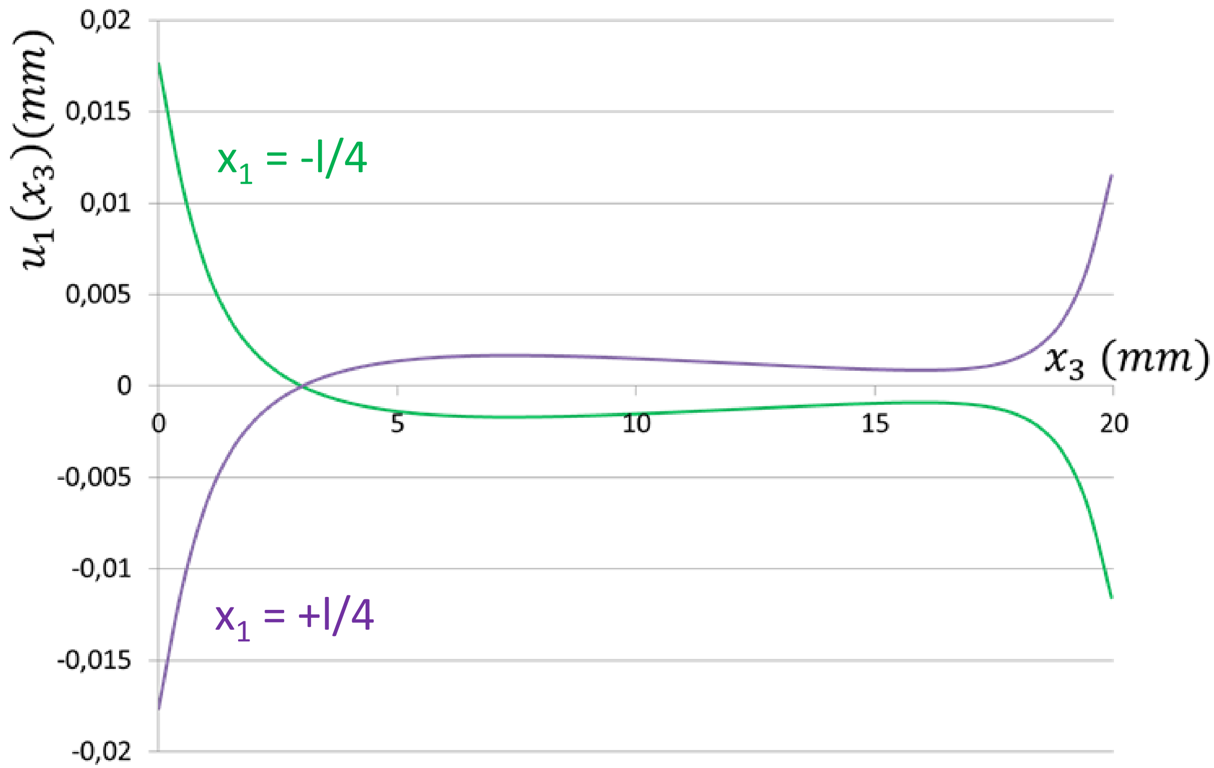
E_{11} = 140 GPa

G_{13} = 3.5 Gpa



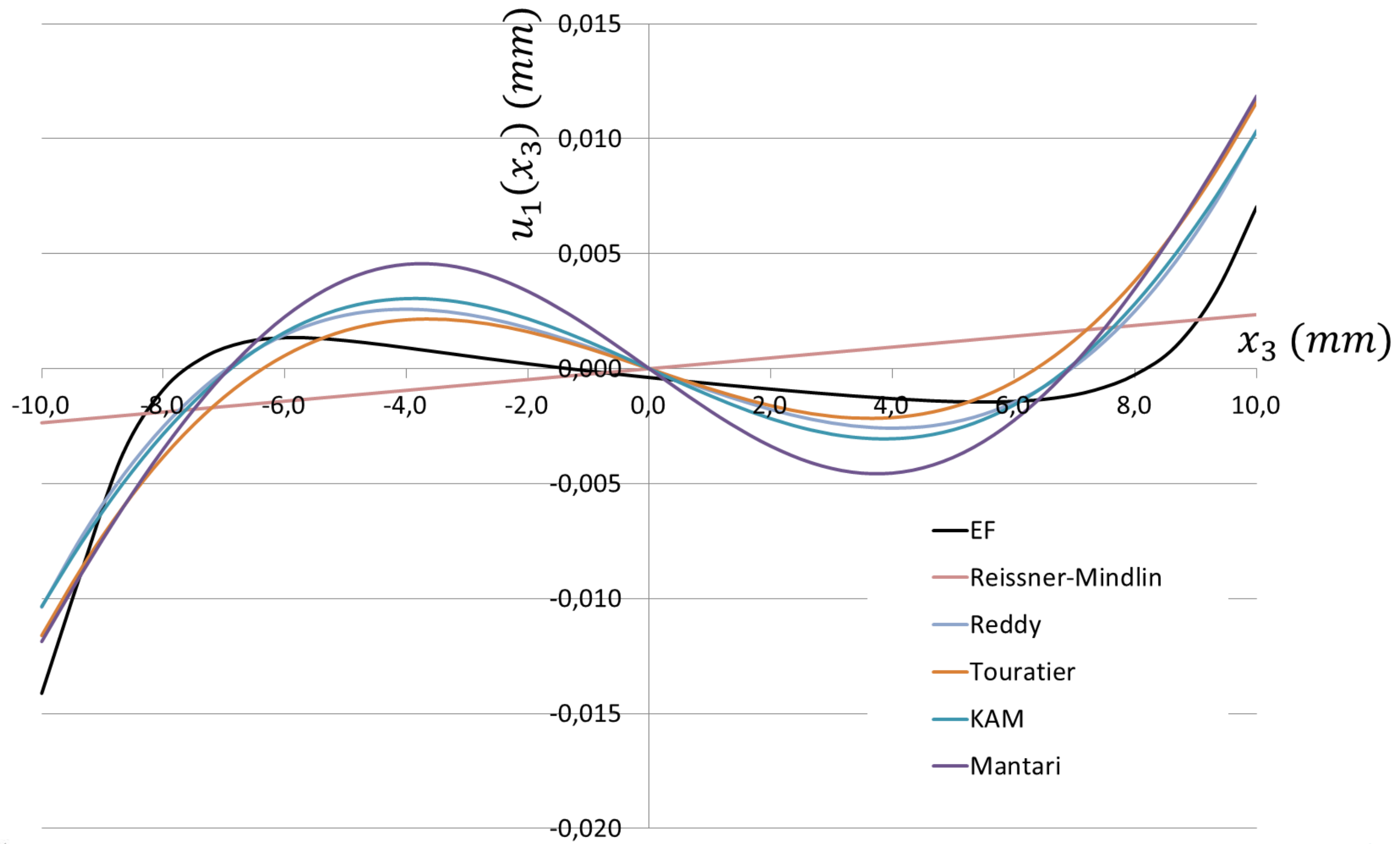
Numerical Modelling

- FEM : Reference results



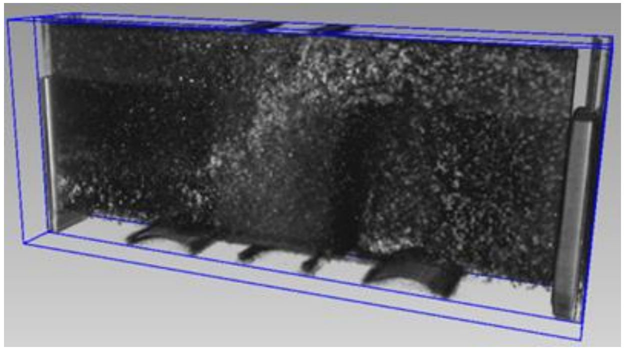
Numerical Modelling

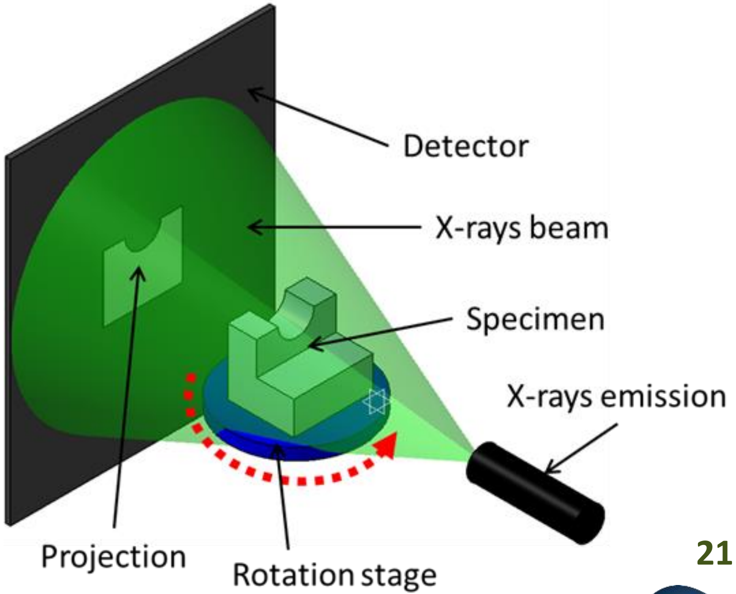
- FEM versus Analytical results



X-RAYS M-COMPUTED TOMOGRAPHY

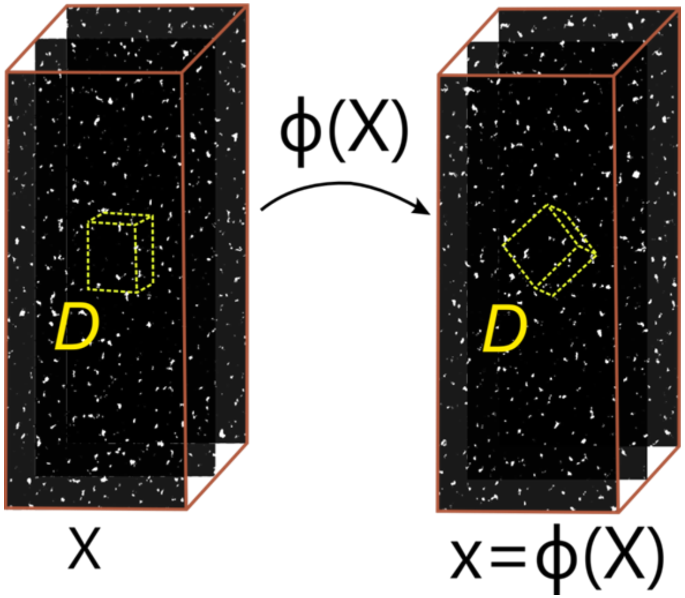
- X-rays transmission through materials
- Reconstruction of radiographies
- Long time acquisitions





DIGITAL VOLUME CORRELATION

- Extension of DIC (2D)
- Metallic markers
- Full 3D displacements
- Variation of voxels grey levels

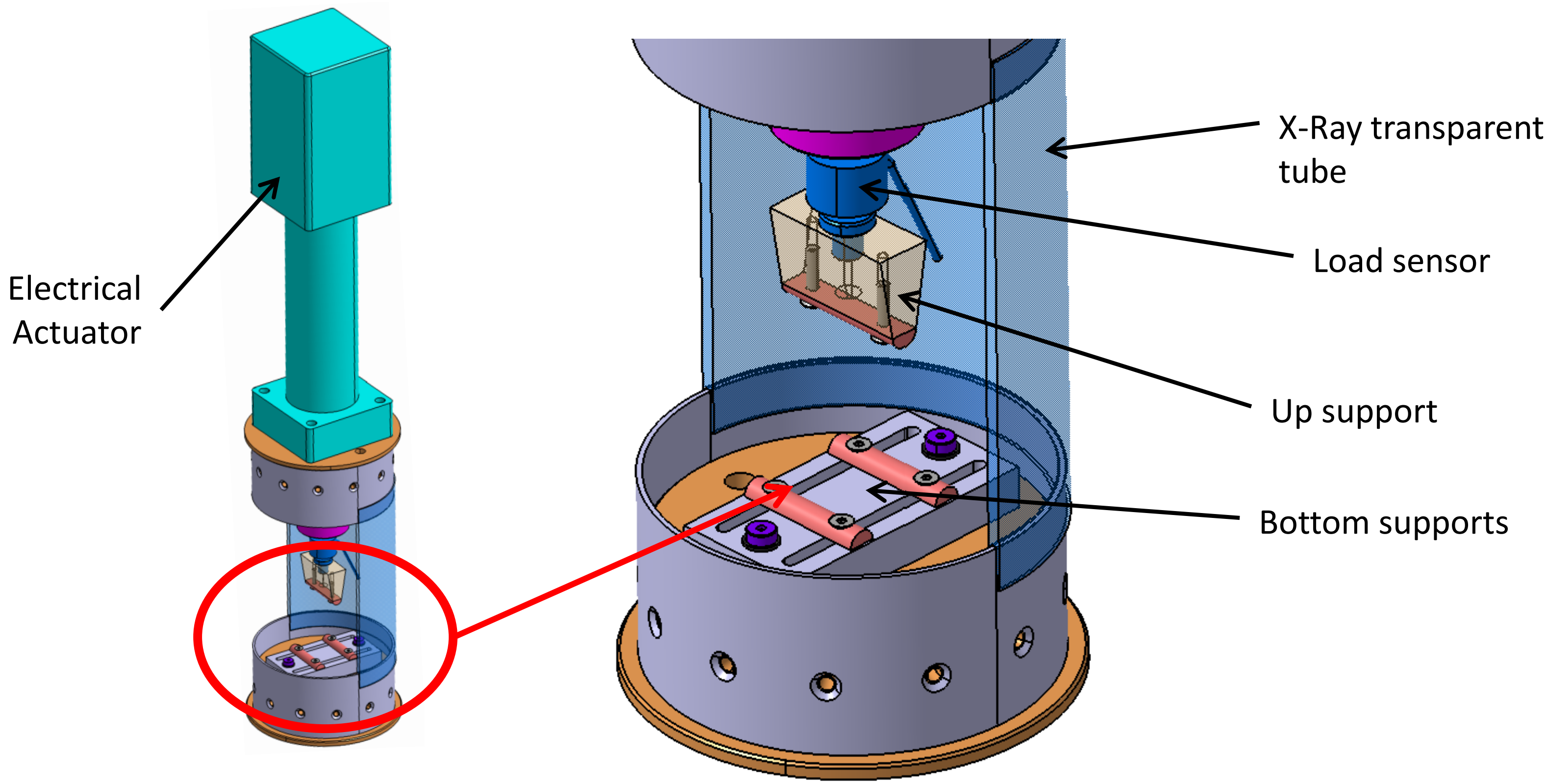


In-Situ Loading System

- Specific Characteristics
  - 130x130x200 mm available
  - 15 kN load capacity
  - 50 mm actuator travel

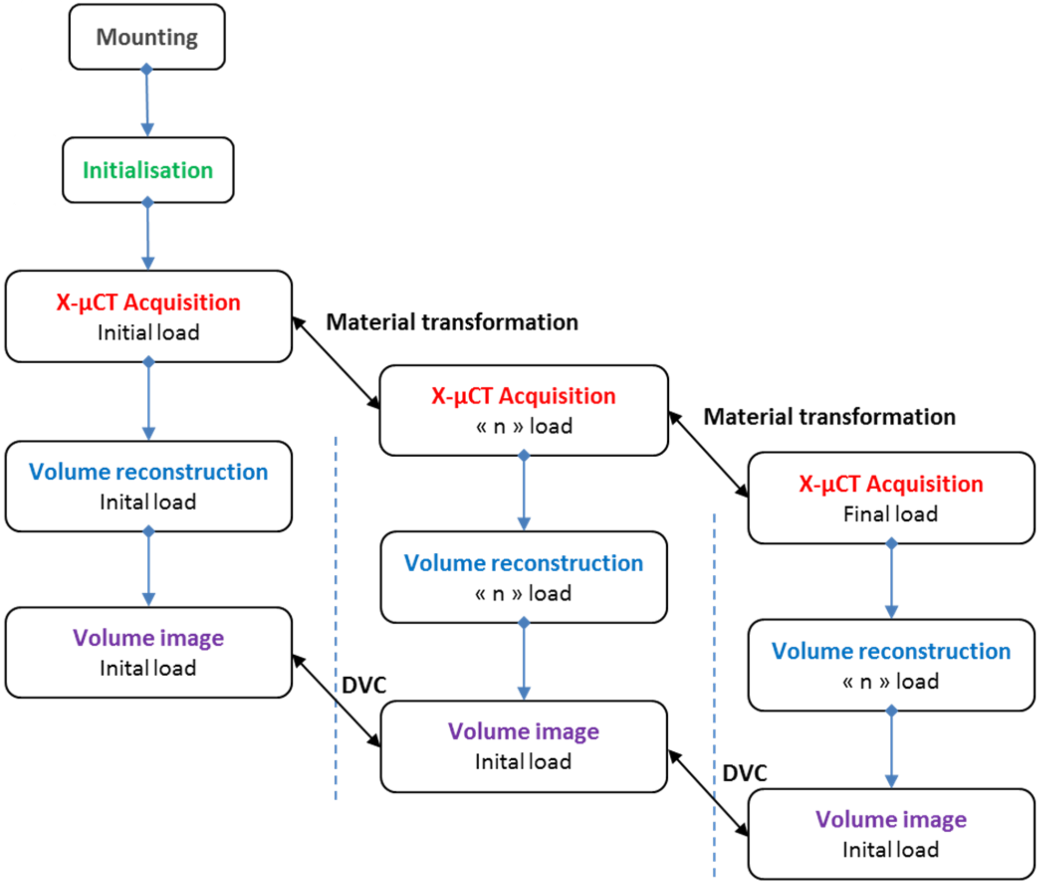
IN-SITU LOADING SYSTEM

- FEM versus Analytical results



EXPERIMENTAL PROTOCOL

- 5 steps experimental protocol

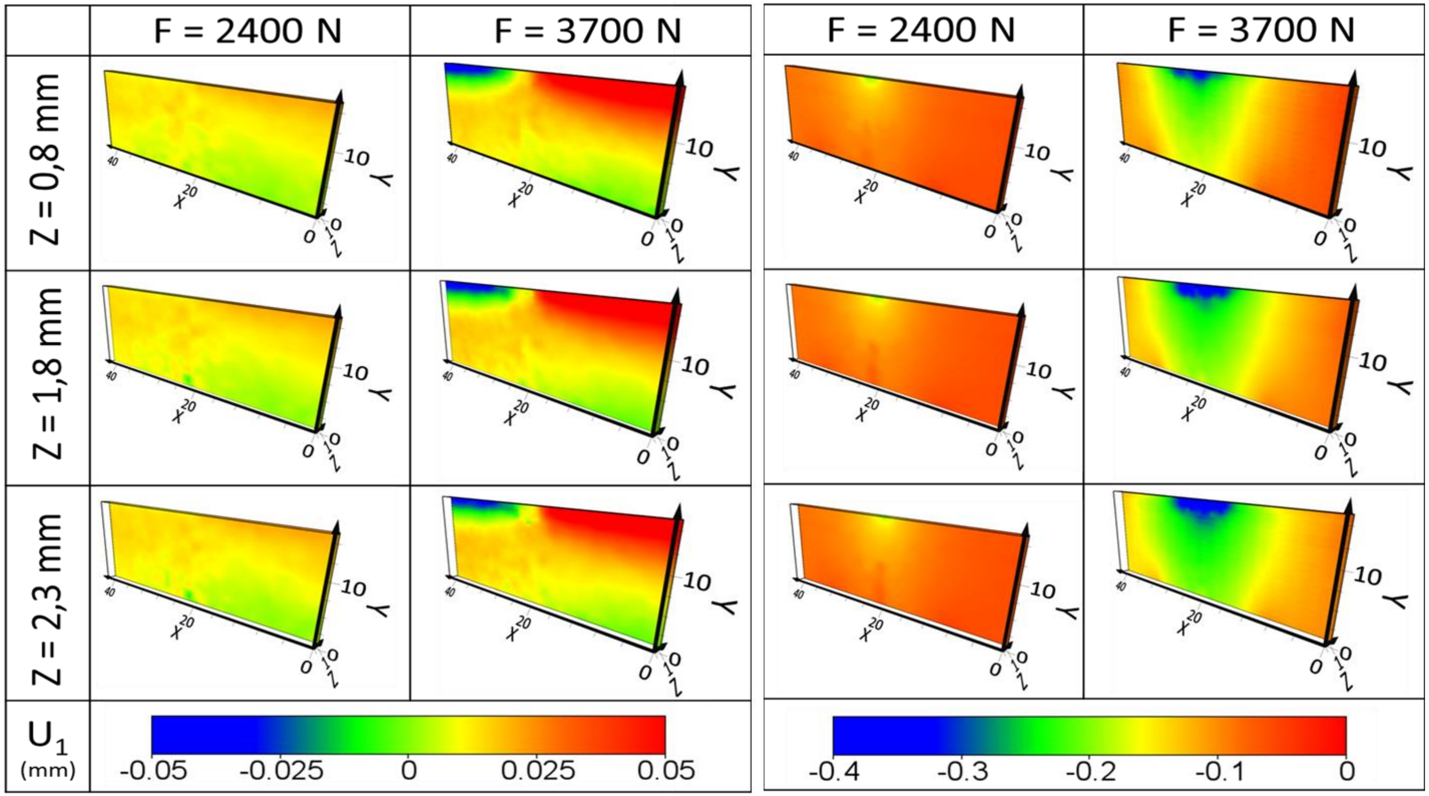


EXPERIMENTAL APPLICATION

- Bending tests sample
- Materials : T700/4090 (carbon/epoxy)
- 5 load steps, between 0 and 2200 N
- Complete acquisition time : 3,5h

RESULTS

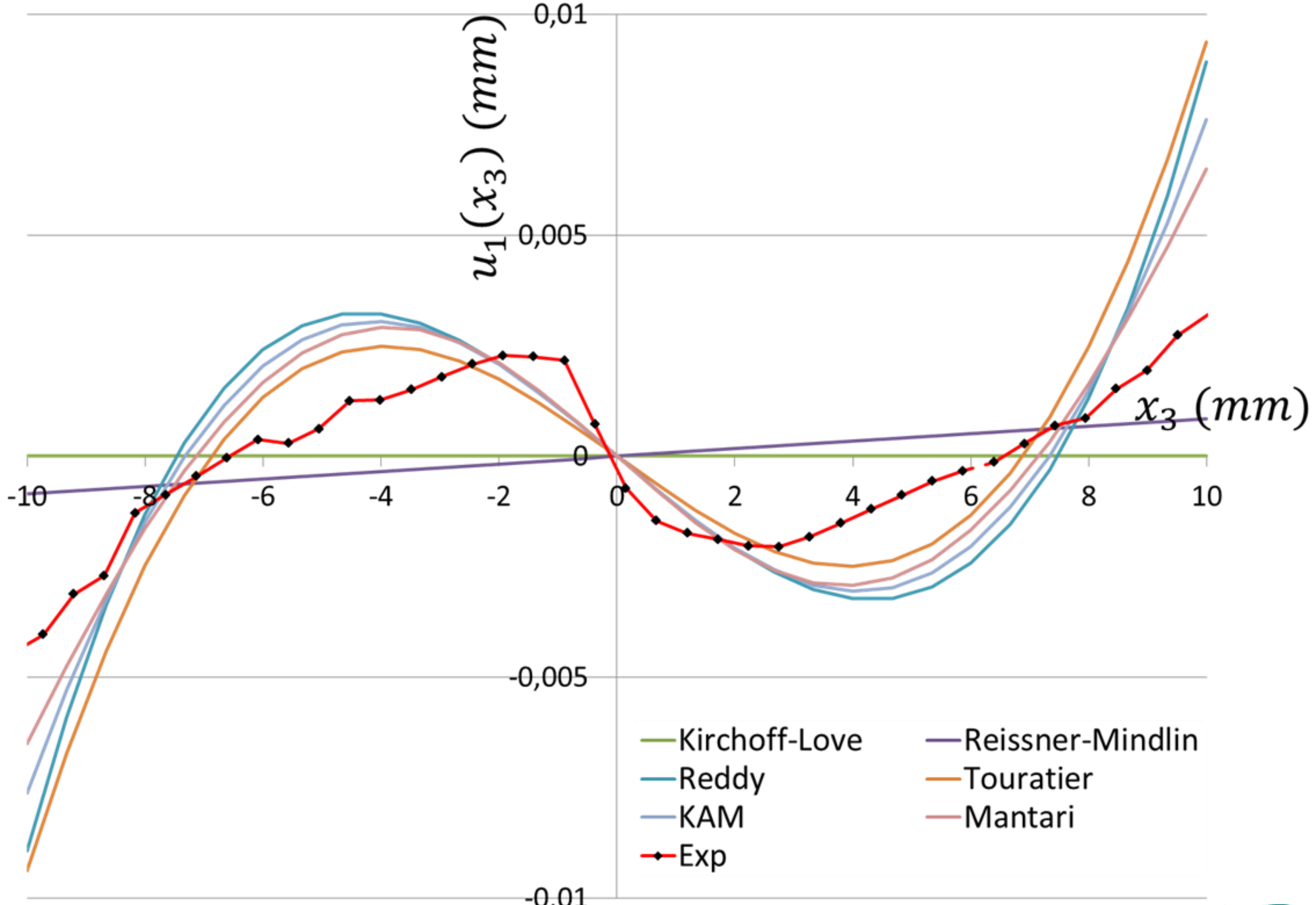
- Volume displacement fields



U_1 (mm) U_3 (mm)

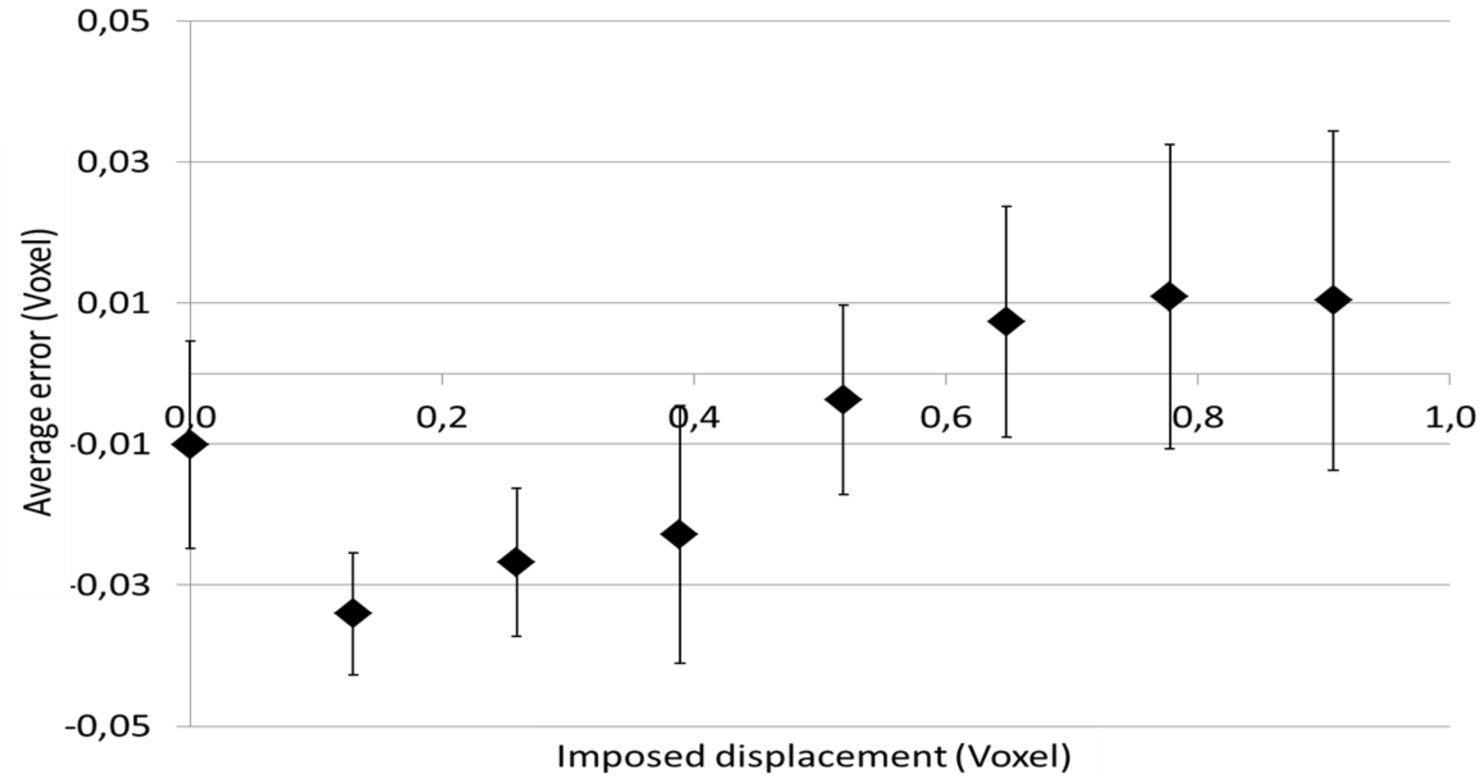
Comparison of Results

- Analytical + FEM + Volume measurements



ACCURACY ASSESSEMENT

- Measurements of imposed rigid body displacements



CONCLUSIONS

- Application of DVC & X-µCT on composite specimens
- Innovant *in-situ* testing device development
- Validation of the experimental procedure
- Good comparison of experimental results
- Validation of refined theories for high warping cases

PERSPECTIVES

- Identification of function $f(x_3)$ from experimental data
- Analysis of different cases by the experimental way
- Application of protocol on industrial structures
- Use volume measurement for mechanical properties identification

Thanks for your attention.