Nonlinear analysis of tape springs: Comparison of two geometrically exact finite element formulations

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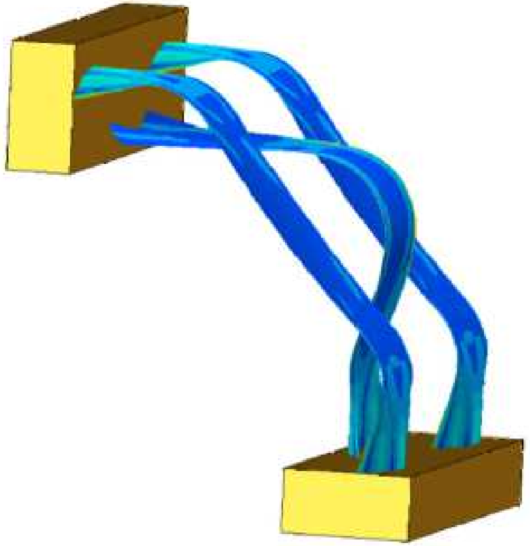
Outline

- Tape springs
- Motivations for a formulation of shells on the special Euclidean group
- Comparison with a classical formulation
  - Test cases
  - Tape springs
- Conclusions

Tape springs – Main features

Definition: Thin plate curved along its width used as a compliant mechanism characterised by its elastic deformation

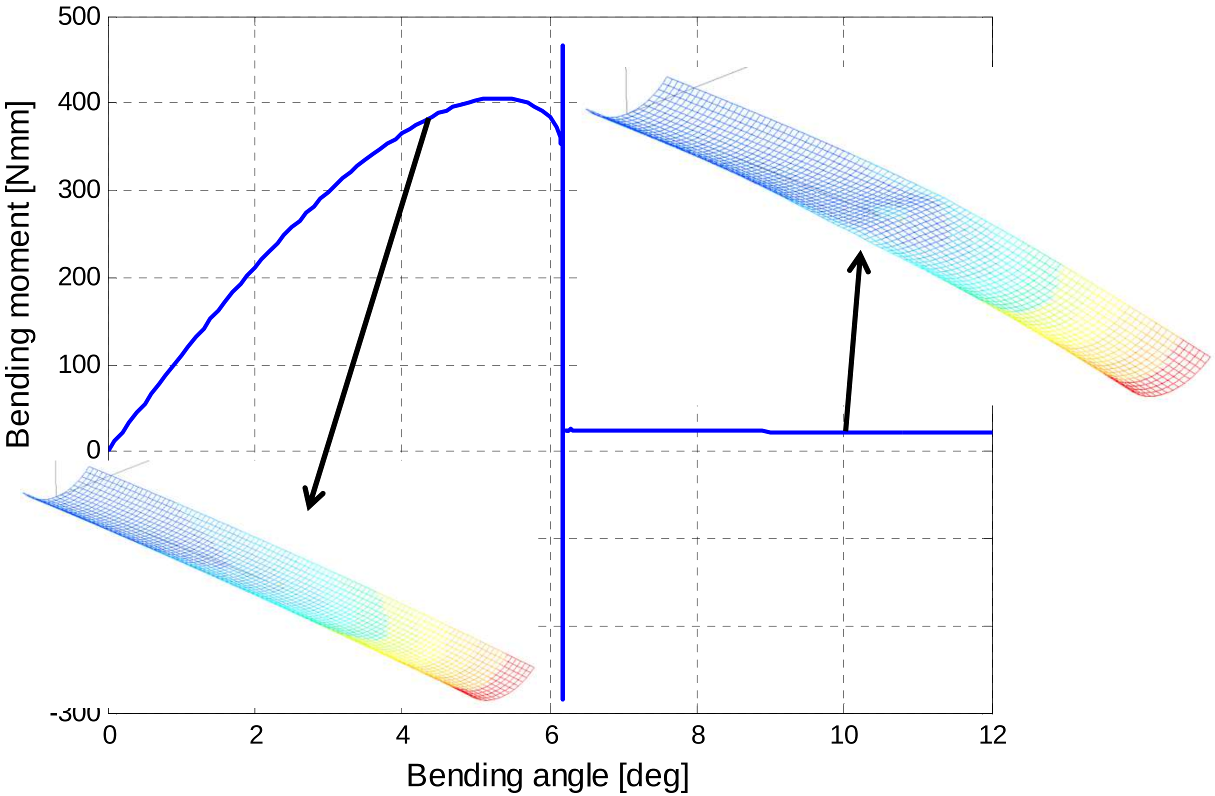


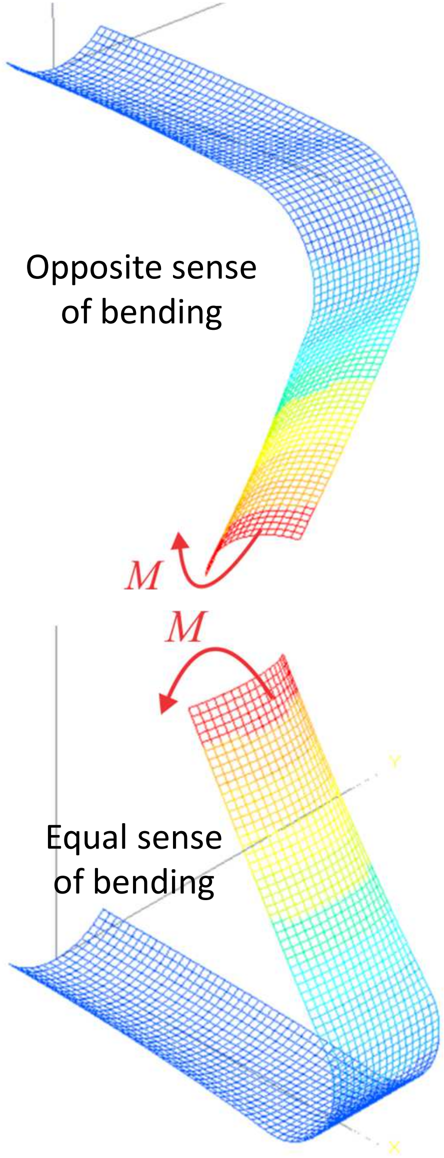
General characteristics:

- Elastic energy
- Deformation
- No external energy sources
- Space applications

Tape springs – Mechanical behaviour

- Nonlinear behaviour
- Buckling, hysteresis and self-locking phenomena
- Senses of bending





Formulation of shells on $SE(3)$

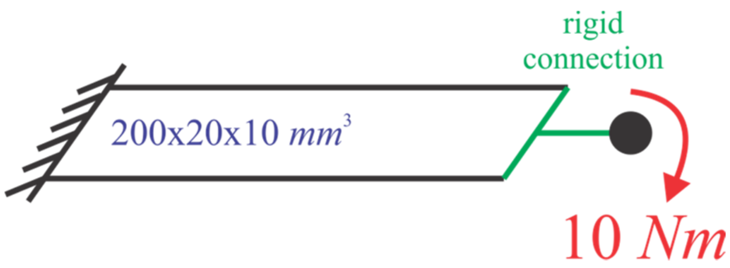
Motivations:

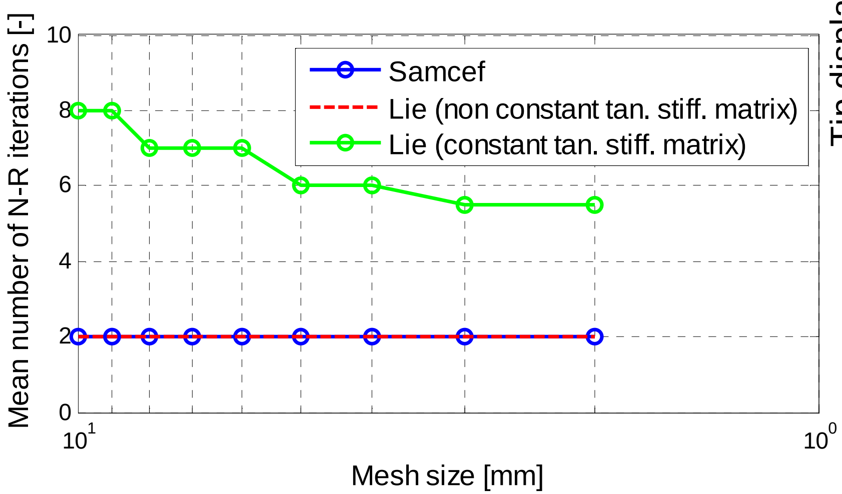
- Framework based on the **Lie group theory** where rotations and translations are treated in a **unified and frame invariant way**
- Equilibrium equations formulated in a **parameterization-free** way
- **Singularities** due to rotation parameterization naturally **avoided**
- Significant **reduction of the geometrical nonlinearities**
- **Locking-free** and **coupled nonlinear interpolation field** for translations and rotations
- **No need to update the tangent stiffness matrix** at each iteration/time step

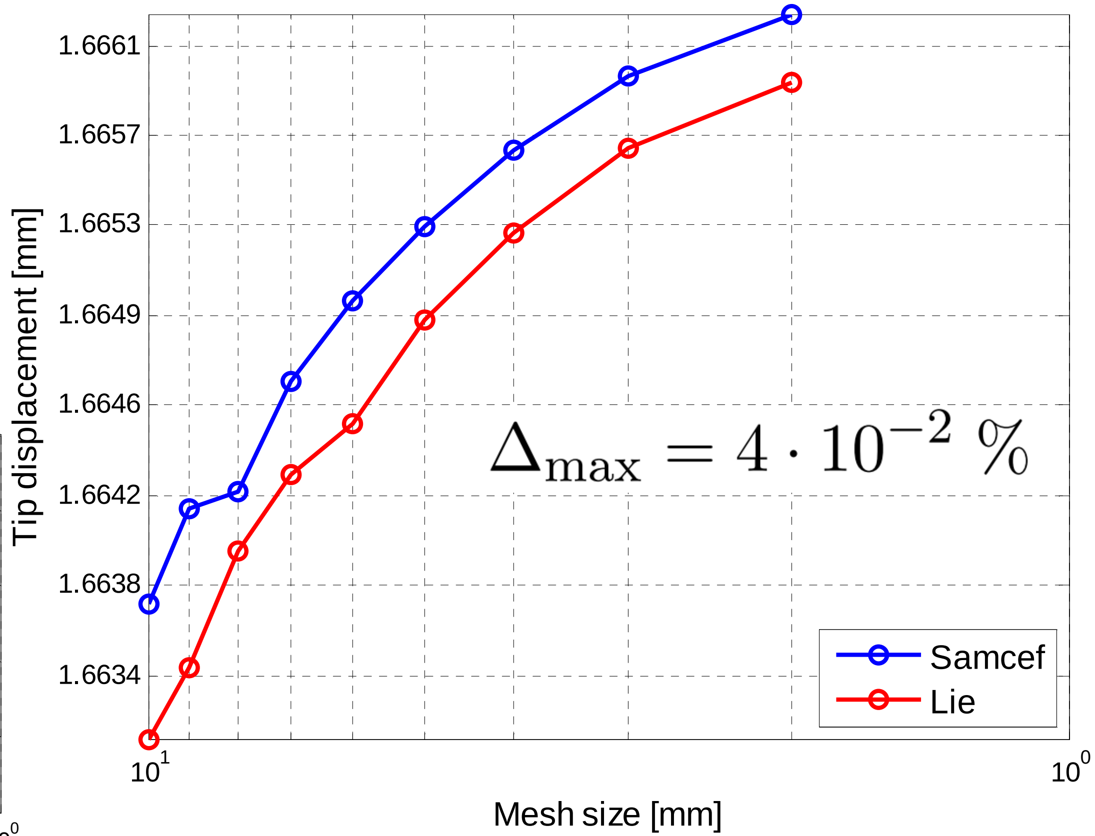
Comparison with a classical formulation

Classical formulation = use of the commercial software SAMCEF in which shells are based on the Mindlin-Reissner model

Flat plate with a lumped mass submitted to bending (10 *Nm*)







$$\Delta_{\max} = 4 \cdot 10^{-2}\ \%$$

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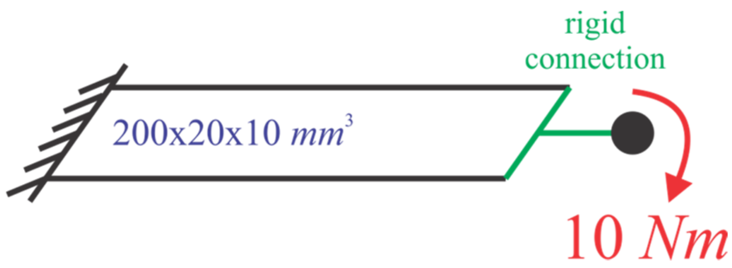
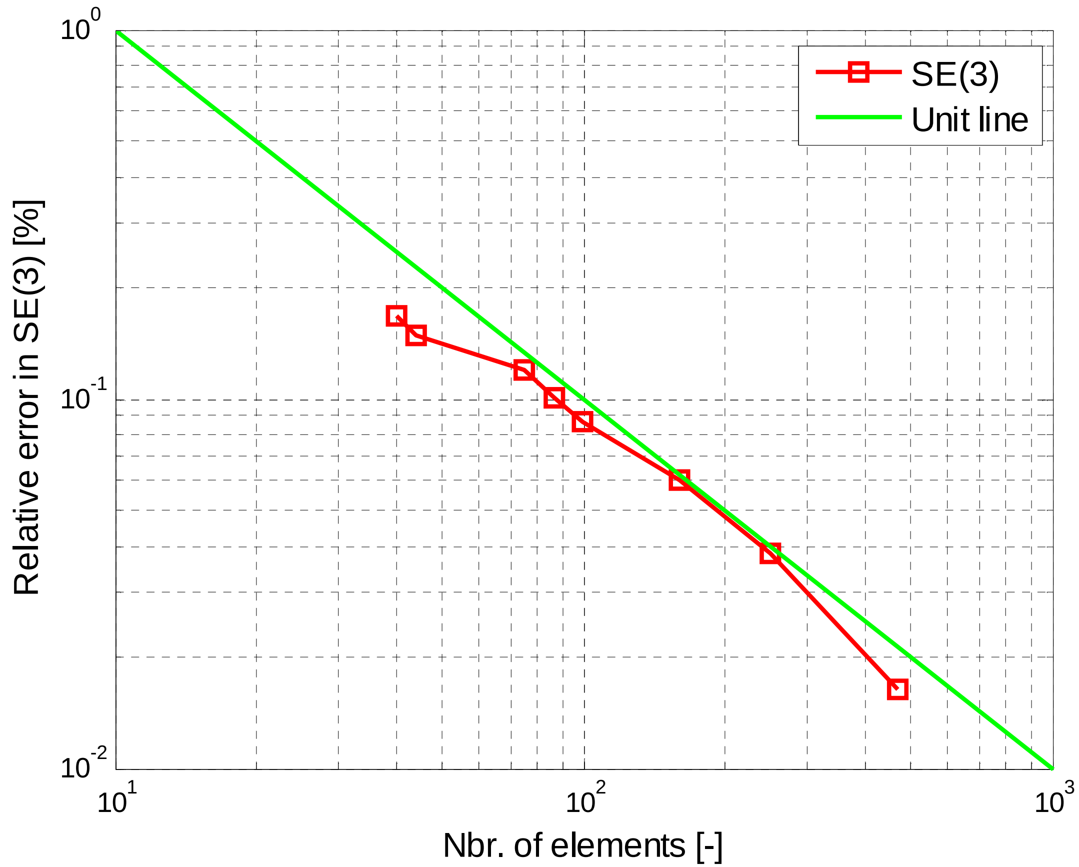
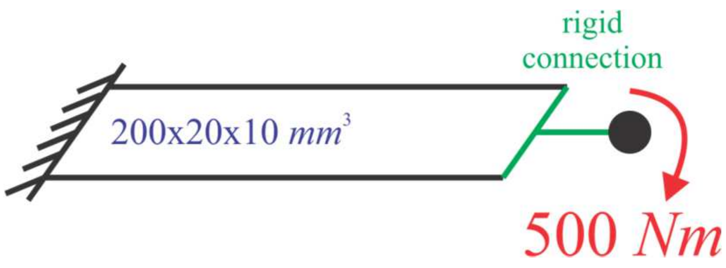
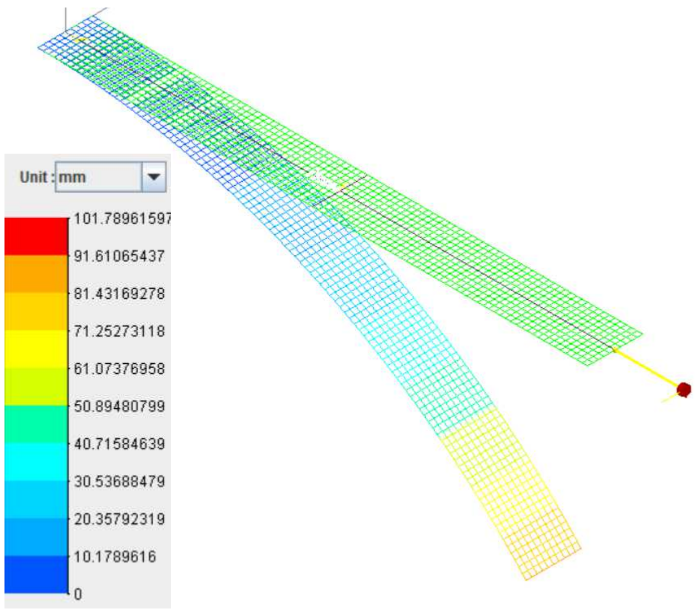


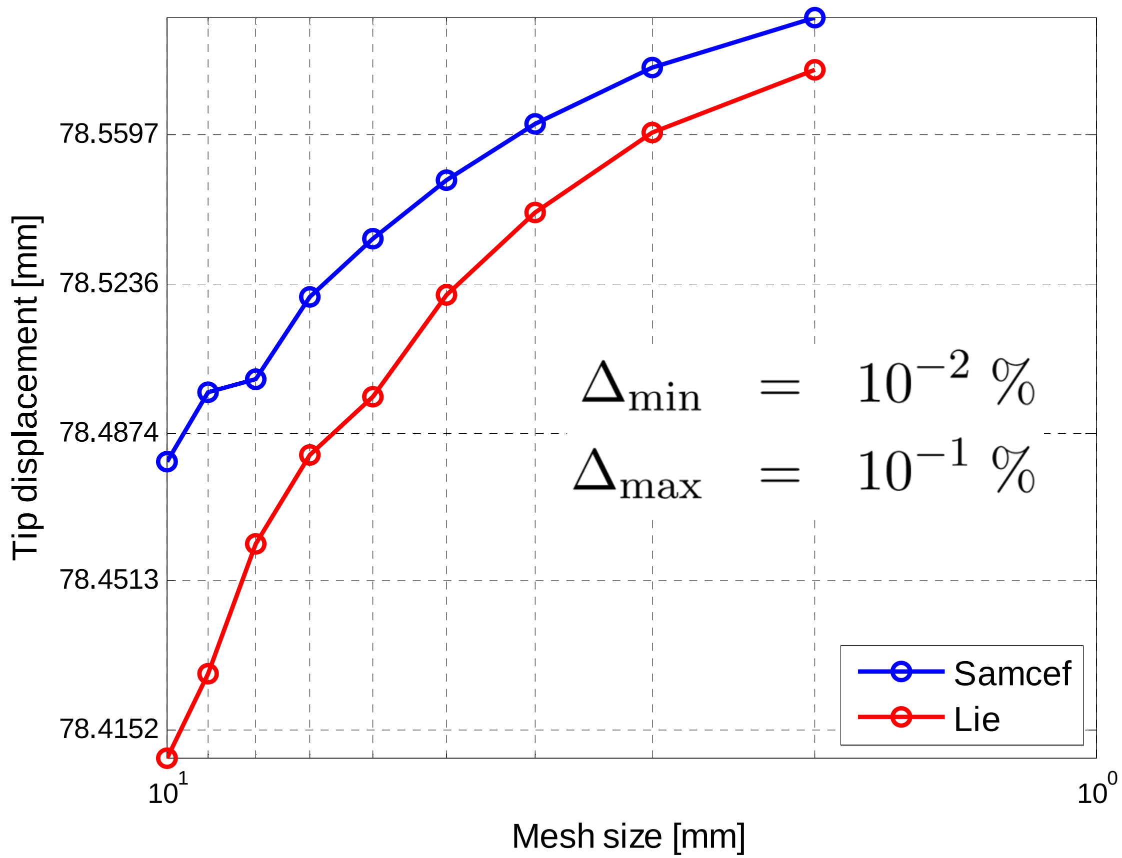


Comparison with a classical formulation

Flat plate with a lumped mass submitted to bending (500 *Nm*)







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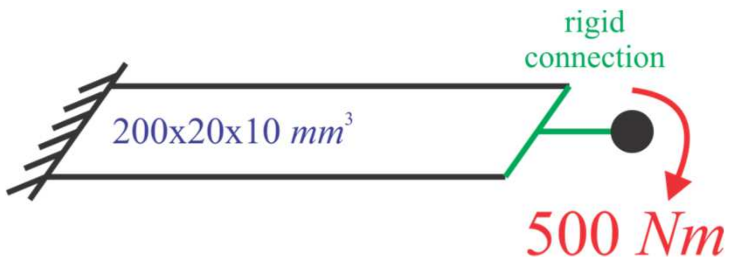
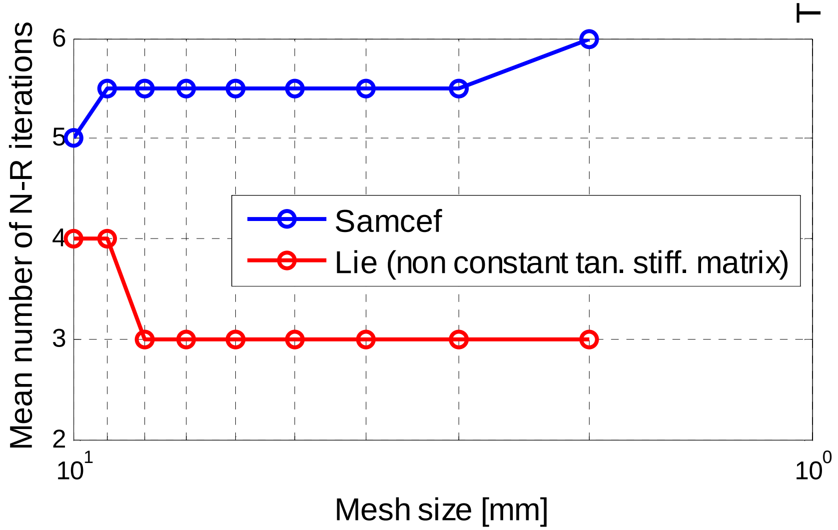
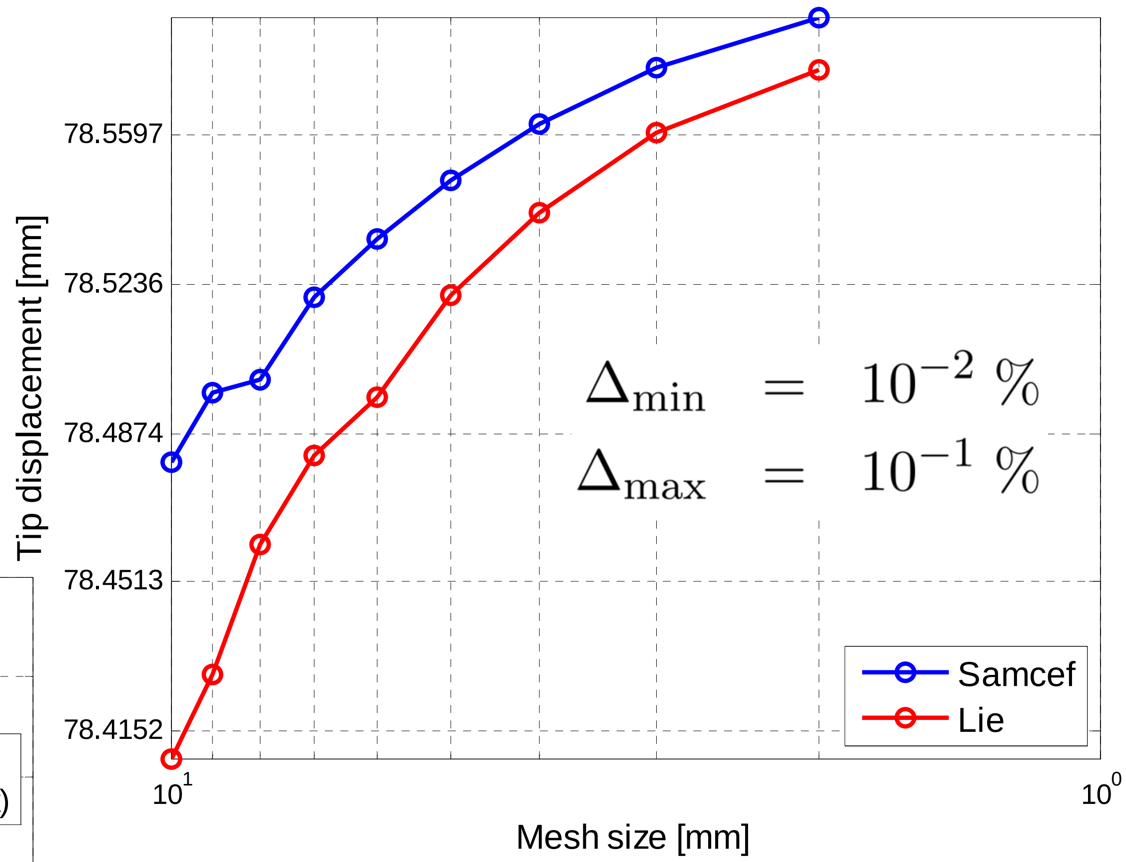
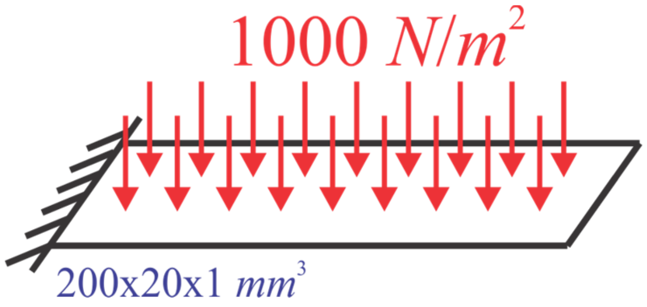


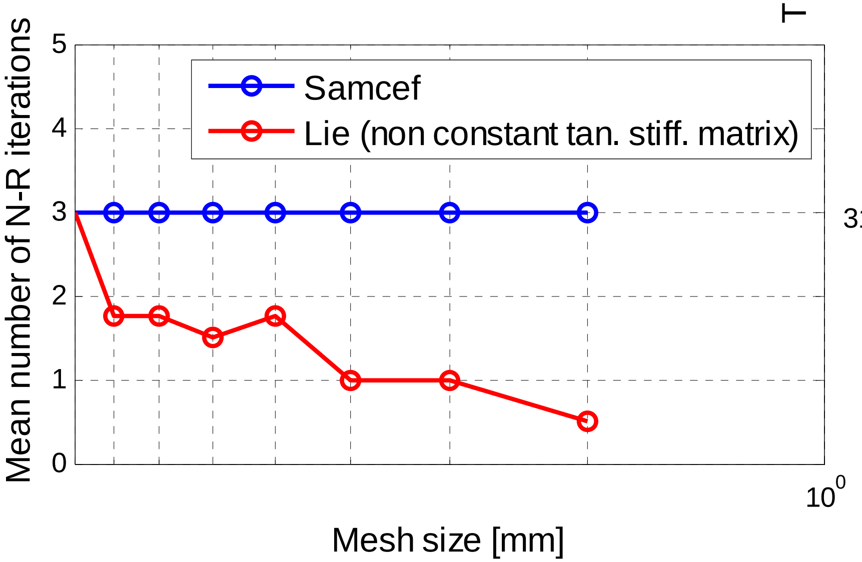


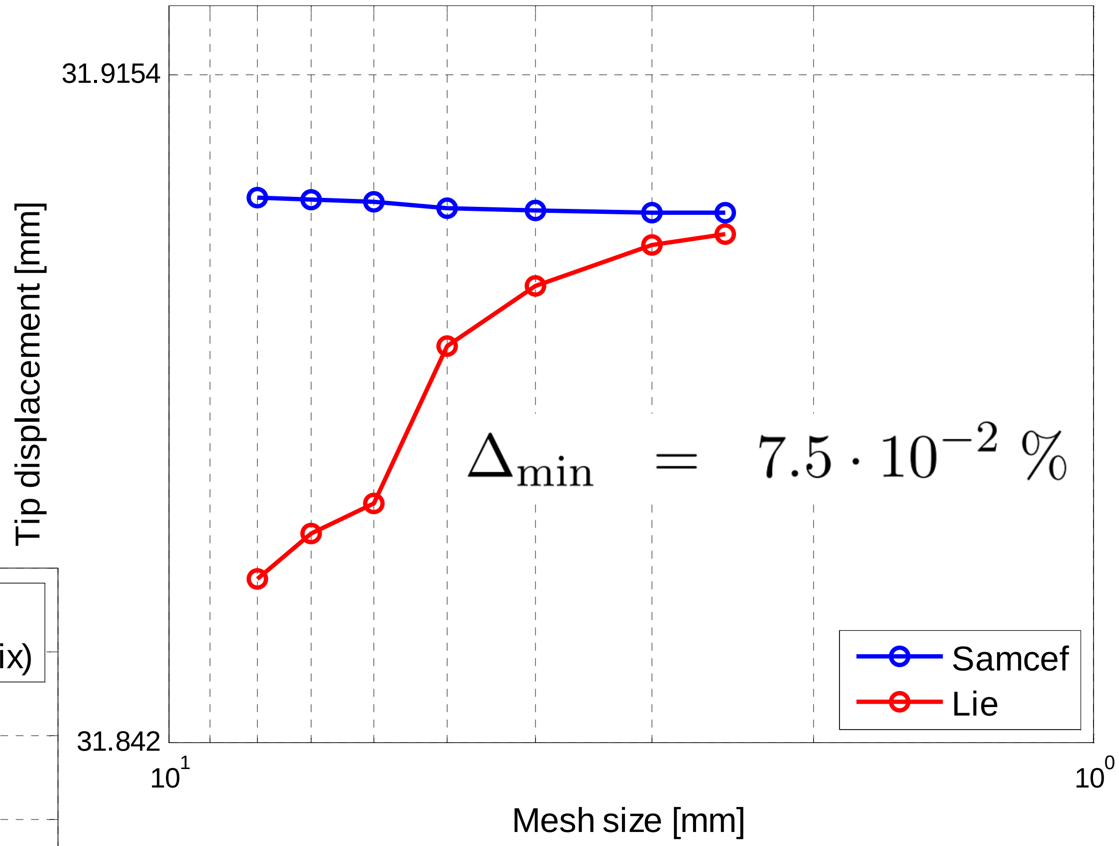


Comparison with a classical formulation

Flat plate submitted to a surface force (1000 N/m²)

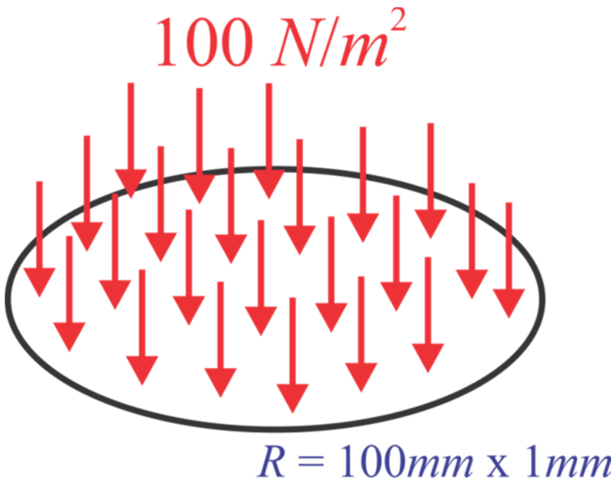


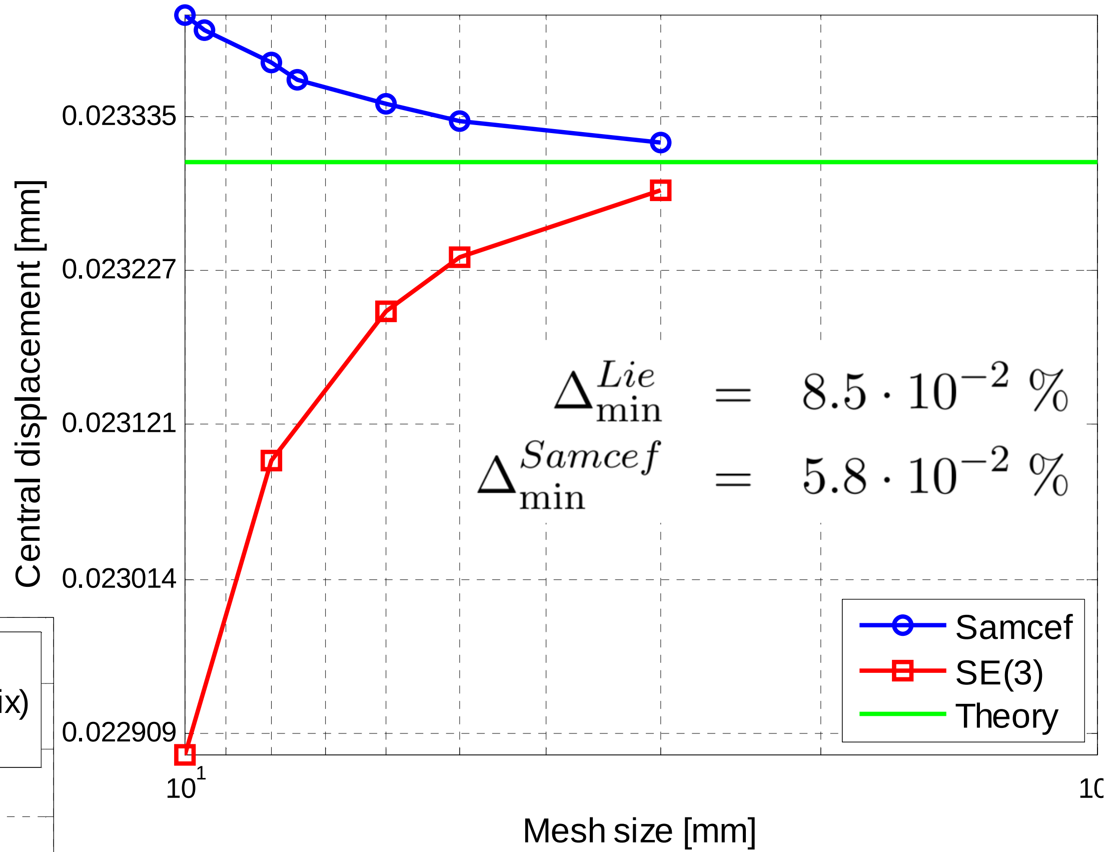


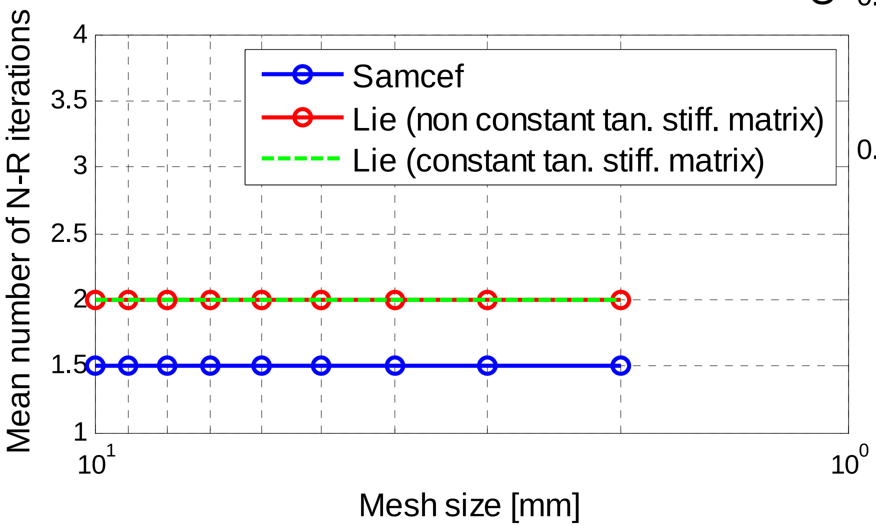


Comparison with a classical formulation

Circular plate submitted to a surface force (100 N/m²)

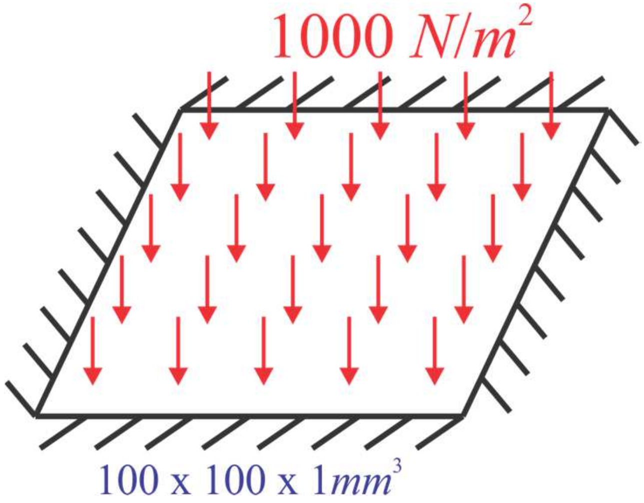


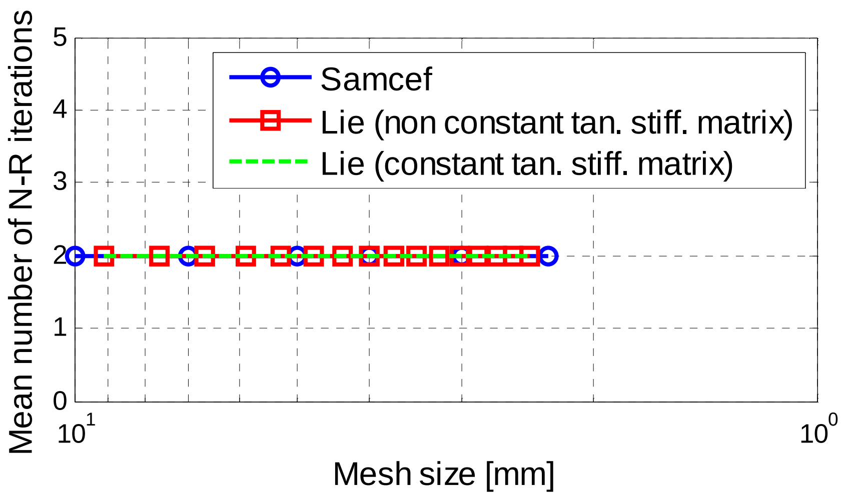


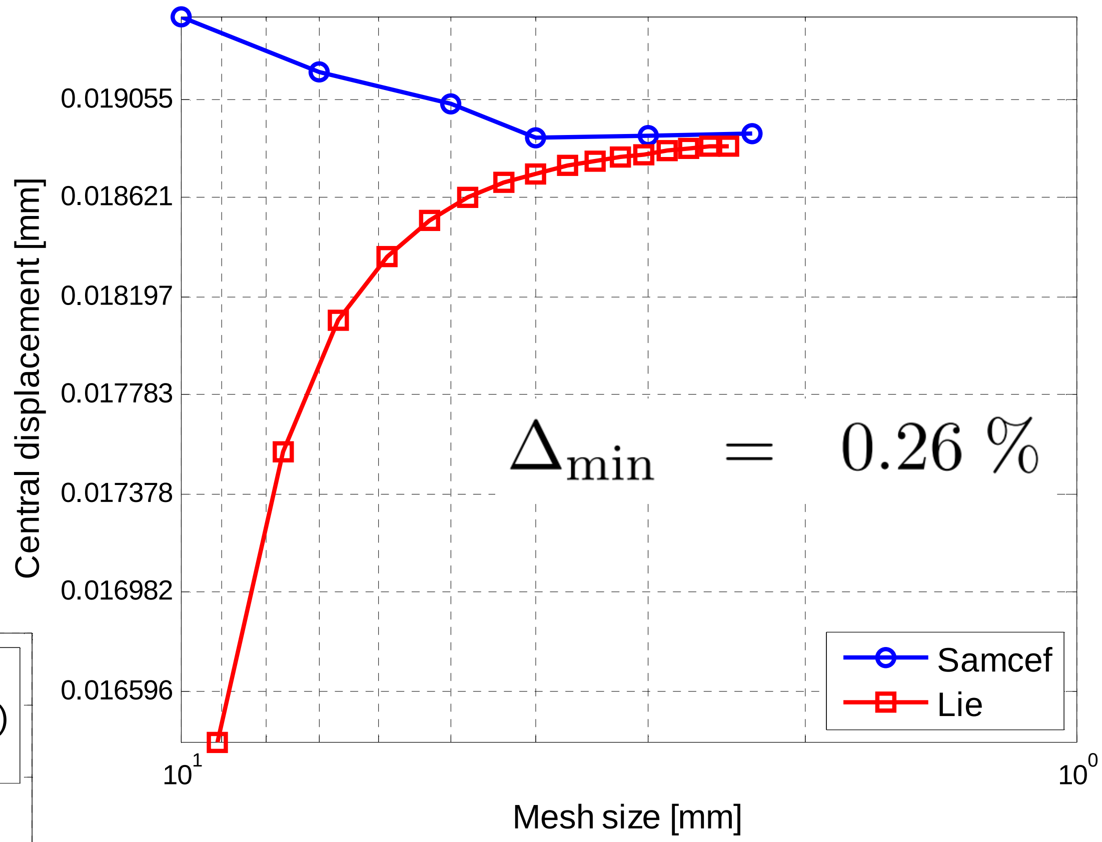


Comparison with a classical formulation

Square plate submitted to a surface force (1000 N/m²)

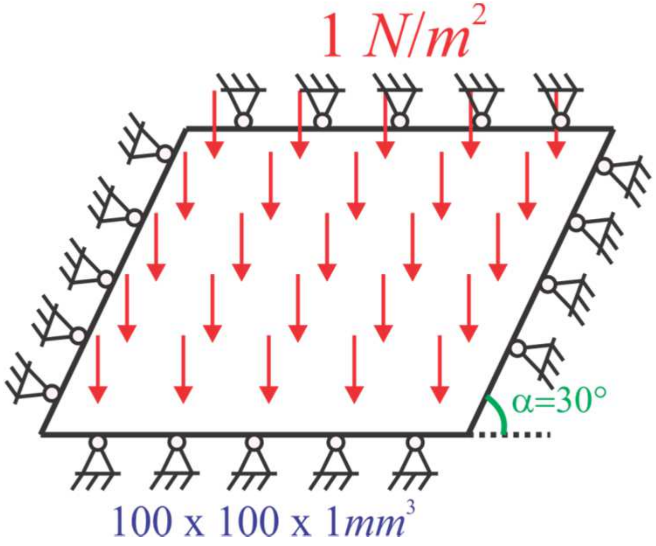


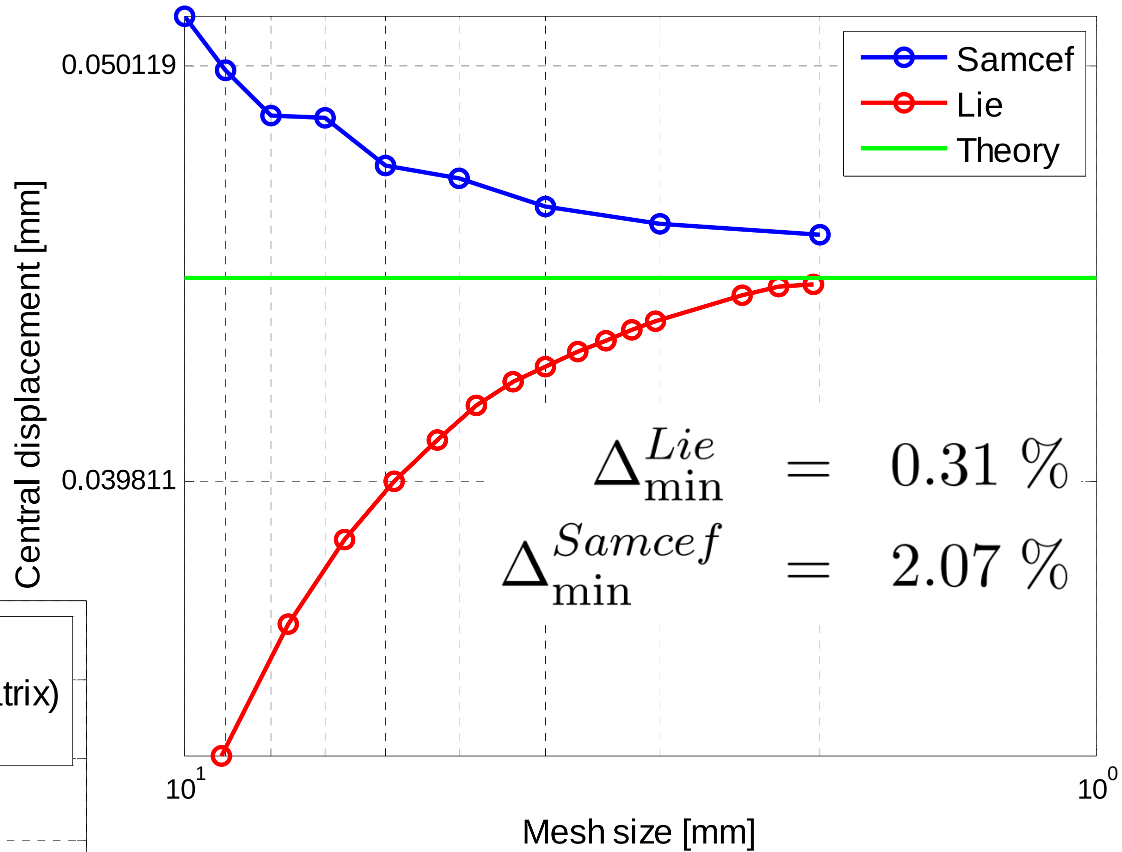


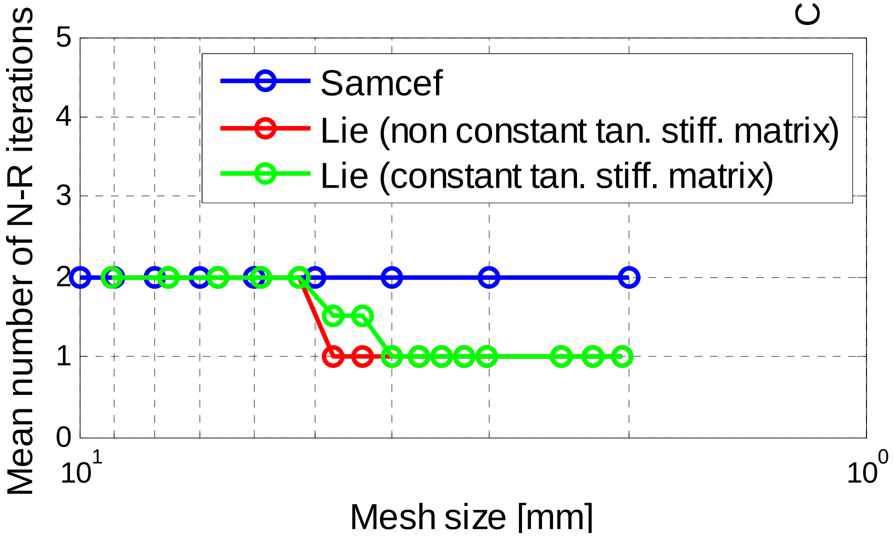


Comparison with a classical formulation

Rhombic plate submitted to a surface force (1 N/m²)

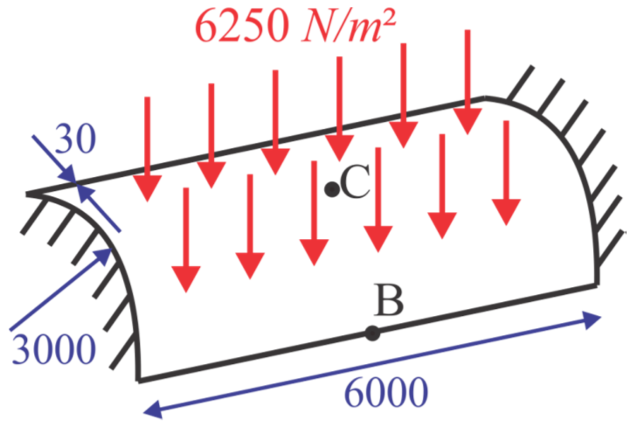


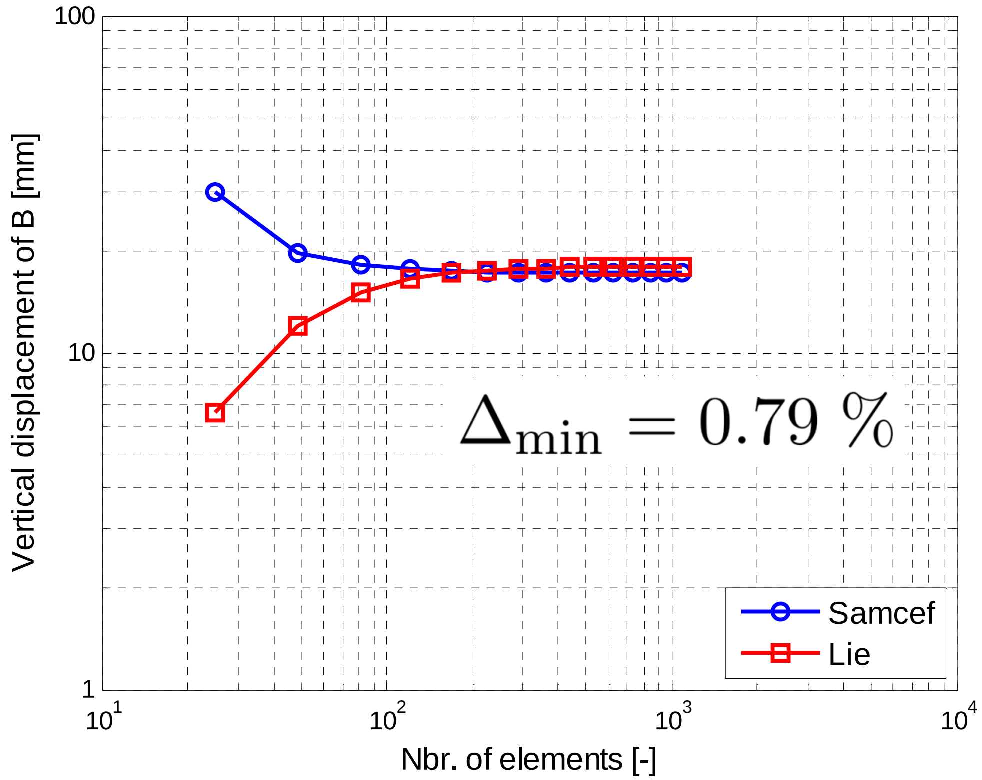


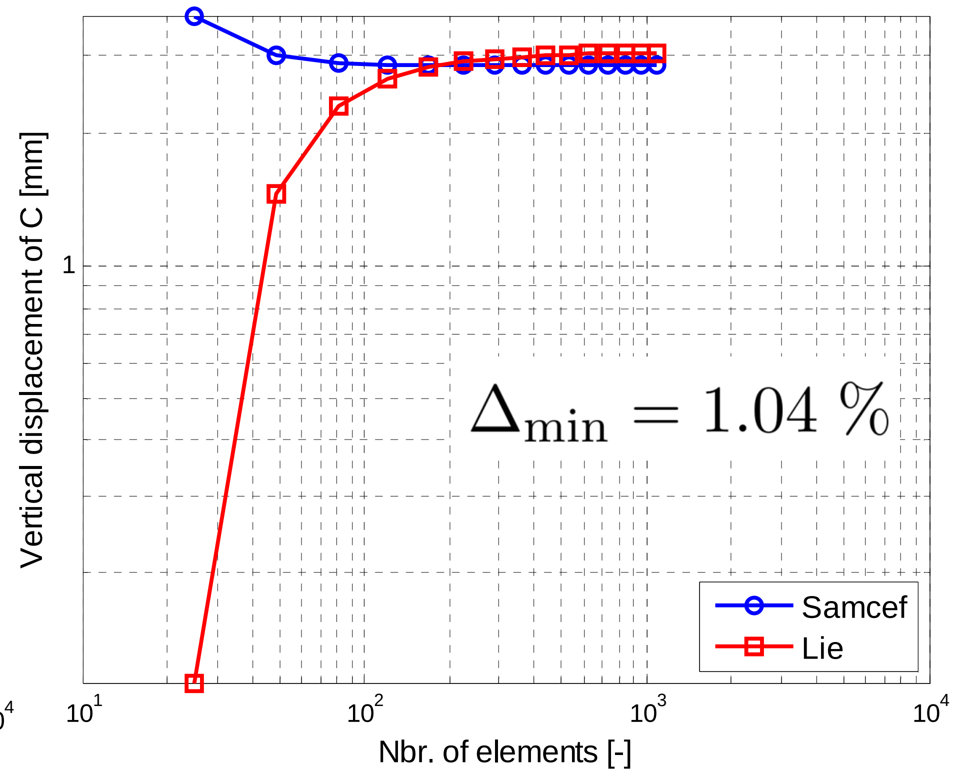


Comparison with a classical formulation

Barrel roof submitted to a surface force (6250 N/m²)







Comparison with a classical formulation

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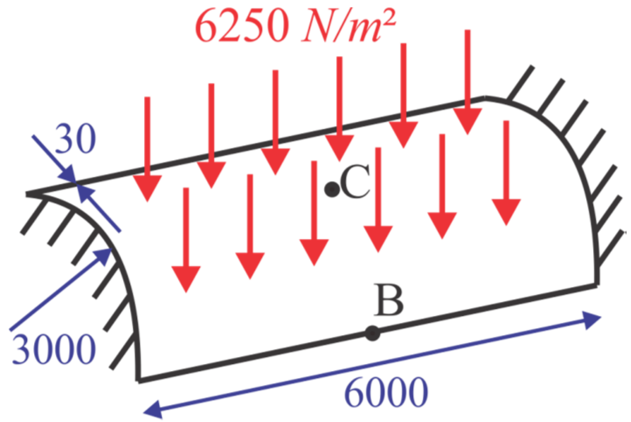
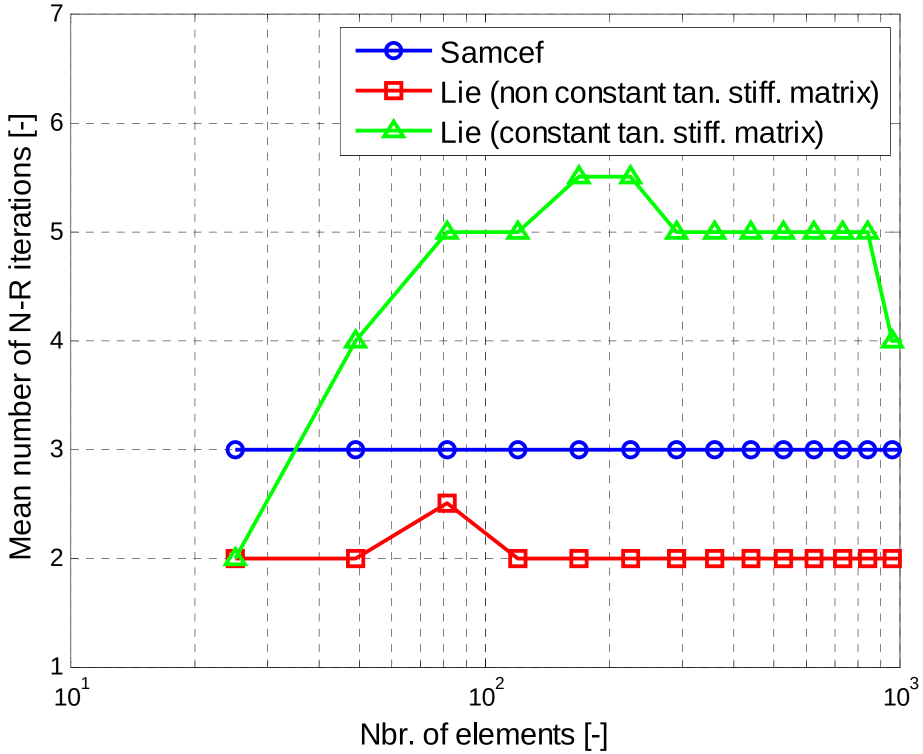
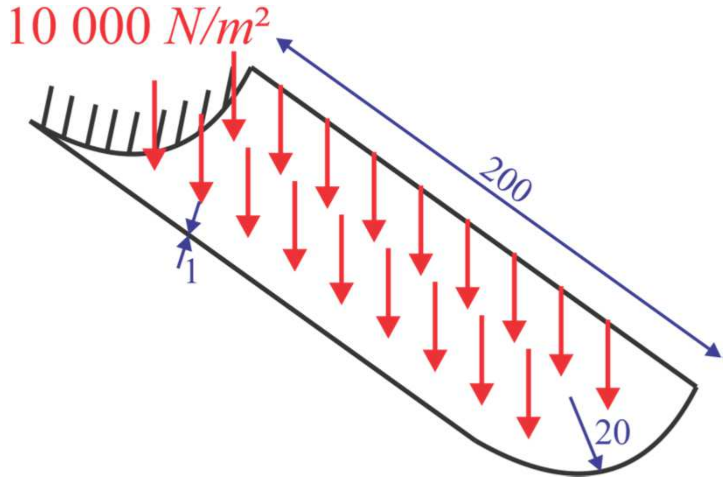
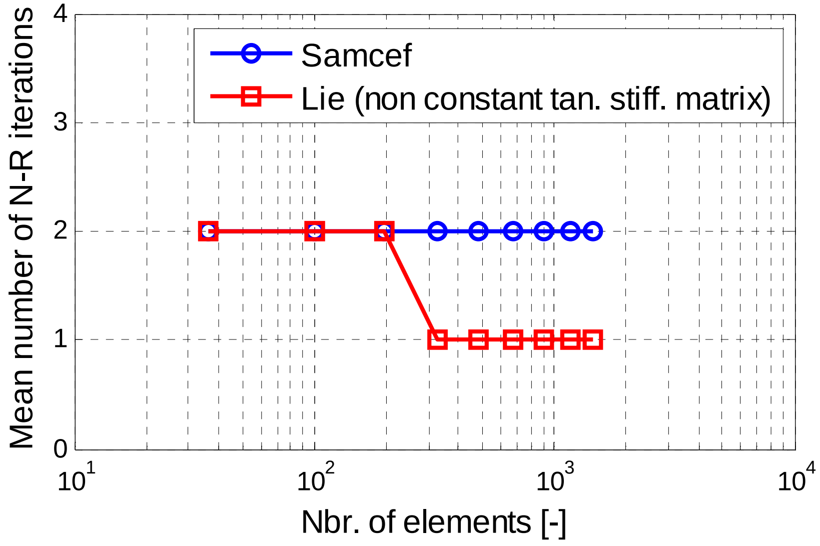


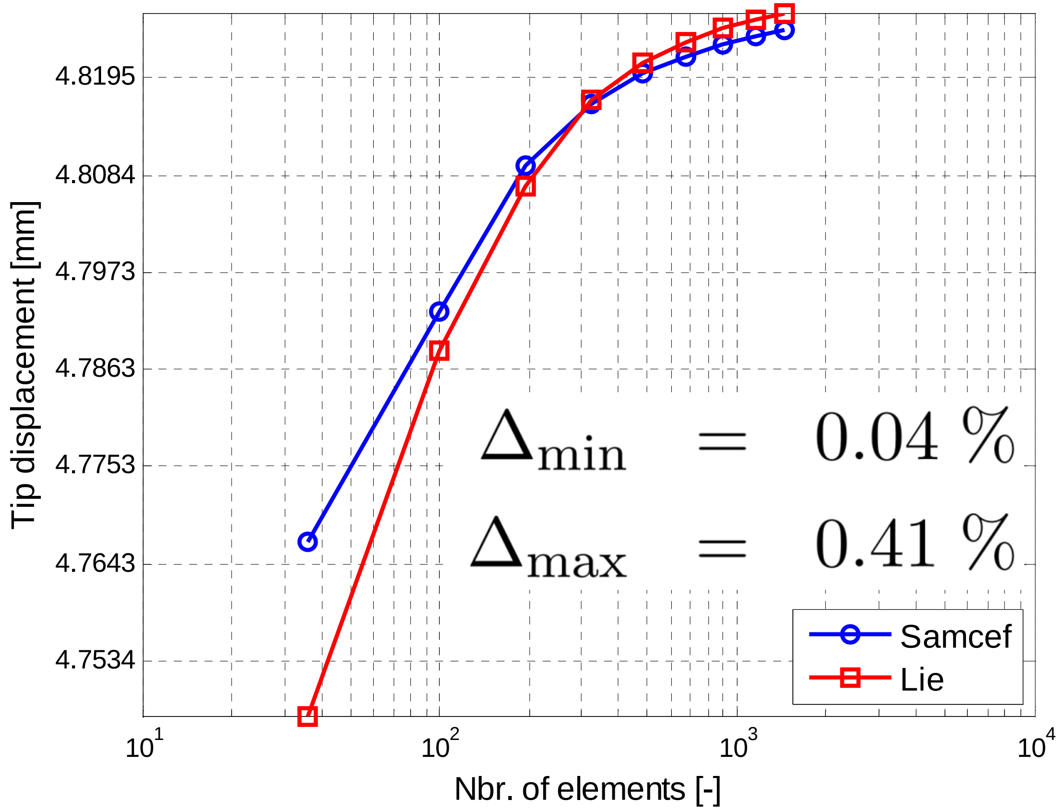


Comparison with a classical formulation

Tape spring submitted to a surface force (10 000 N/m²)







Conclusions

- Convergence to the same results for the formulation on $SE(3)$ and the classical formulation (Samcef)
- No need to always update the tangent stiffness matrix
- Reduction of the amount of geometric nonlinearities
- Good representation of nonlinear behaviours
- Good representation of structures with an initial curvature (tape springs)

Next developments:

- Improvement of the convergence rate
- Dynamic formulation
- Add a continuation method to model the buckling in tape springs

Thank you for your attention

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