Importance of structural damping in the dynamic analysis of compliant deployable structures

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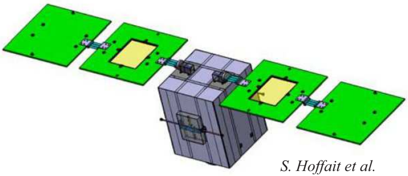
Outline

INTRODUCTION - TAPE SPRINGS

Definition: Thin strip curved along is width used as a compliant mechanism

General characteristics:

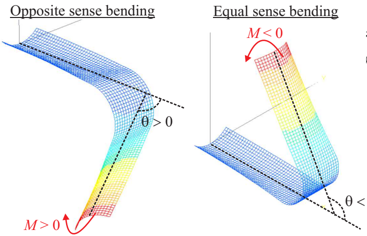
- Elastic energy
- Structural deformation
- No external energy sources
- Cheap, simple, reliable
- Space applications

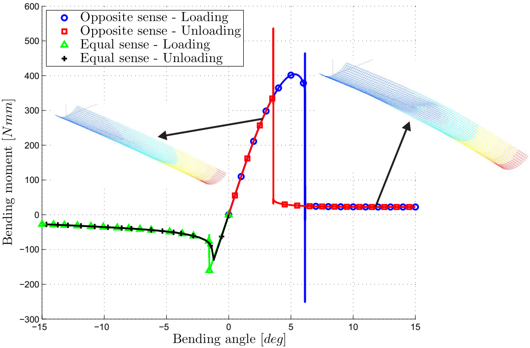


S. Hoffait et al.

INTRODUCTION - TAPE SPRINGS

- Highly nonlinear
- Buckling, hysteresis and self-locking
- Senses of bending





INTRODUCTION - TYPES OF DAMPING

Structural damping:

- Property of the material
- Simple rheological models: Maxwell, Kelvin-Voigt, ...
- Advanced models: Prony series, Rayleigh damping, ...

Numerical damping:

- Property of the solver
- Examples: Newmark, HHT, generalized-α, Runge Kutta, ...
- Role: convergence, filter spurious modes, ...

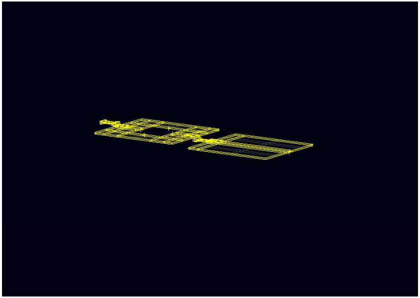
Objectives

State of the art:

- In the majority of the previous works, F. E. analyses with numerical damping
- Structural damping rarely represented
- Notable exceptions: Kwok & Pellegrino (2011) and Mobrem & Adams (2009)

Objectives:

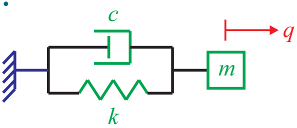
- Determine the impact of the two types of damping
- Introduce some structural damping
- Reduce the dependence to numerical damping



Simulation without structural damping (*Hoffait et al.*).

ONE DEGREE OF FREEDOM SYSTEM

Case study:



$\omega^2 = \frac{k}{m} \quad \varepsilon = \frac{c}{2\omega m}$

Equation of motion:

$$\ddot{q}_{n+1} + 2\varepsilon\omega\dot{q}_{n+1} + \omega^2 q_{n+1} = 0$$

System to be solved: (with the update formulae of the solver)

$$\mathbf{E}(\omega h, \varepsilon)\mathbf{x}_{n+1} = \mathbf{B}(\omega h, \varepsilon)\mathbf{x}_n$$

Amplification matrix:

$$\mathbf{A}(\omega h, \varepsilon) = \mathbf{E}(\omega h, \varepsilon)^{-1}\mathbf{B}(\omega h, \varepsilon)$$

One degree of freedom system

Spectral radius:

$$\rho(\omega h, \varepsilon) = \max(|\lambda_1|, |\lambda_2|, |\lambda_3|)$$

to assess the level of dissipation in the model.

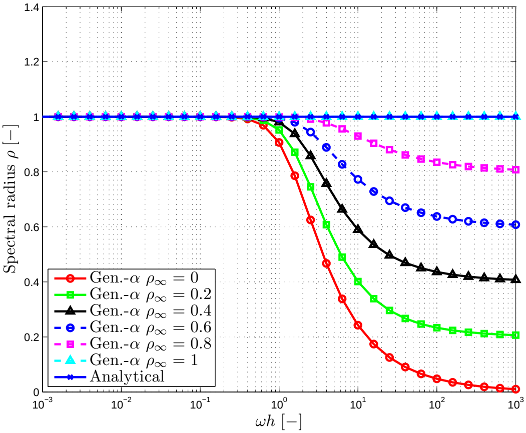
For a valid numerical solution:

Low frequencies $\omega h \lesssim 0.5$	High frequencies $\omega h \gtrsim 2$
Accuracy Good representation of the physical behaviour	Convergence
Good approximation of the real damping	Filtering of high frequency modes

ONE DEGREE OF FREEDOM SYSTEM

Structural damping and numerical damping:

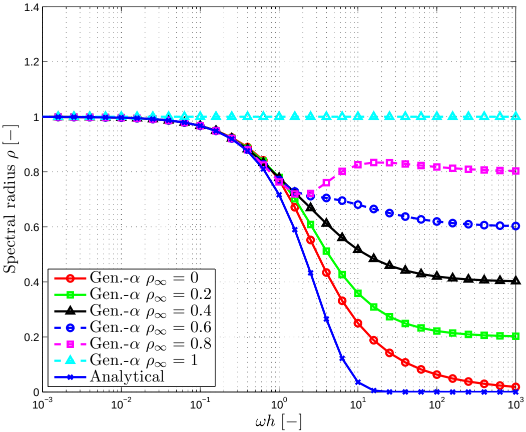
$\varepsilon = 0$ $\quad\quad$ $0 \leq \rho_\infty \leq 1$



ONE DEGREE OF FREEDOM SYSTEM

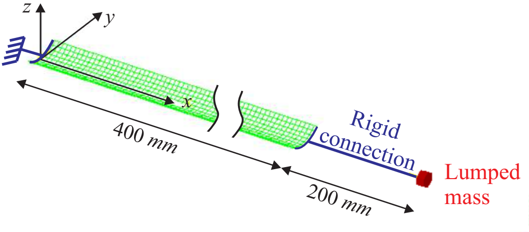
Structural damping and numerical damping:

$\varepsilon = 0.33$ $\qquad 0 \leq \rho_\infty \leq 1$



Tape spring - Dynamic analysis

Case study:

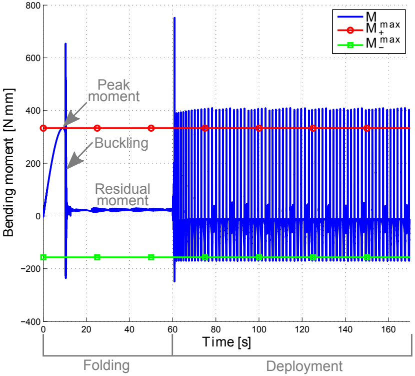


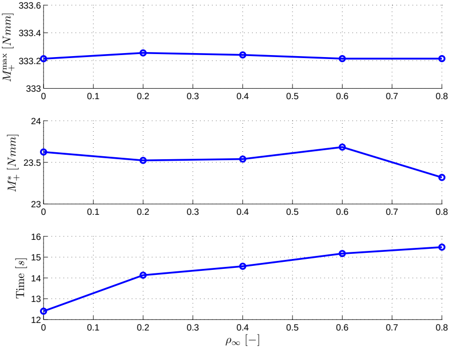
Folding: in the opposite sense with a bending angle of 60°

Deployment: dynamic analysis for 110 *s*

TAPE SPRING - DYNAMIC ANALYSIS

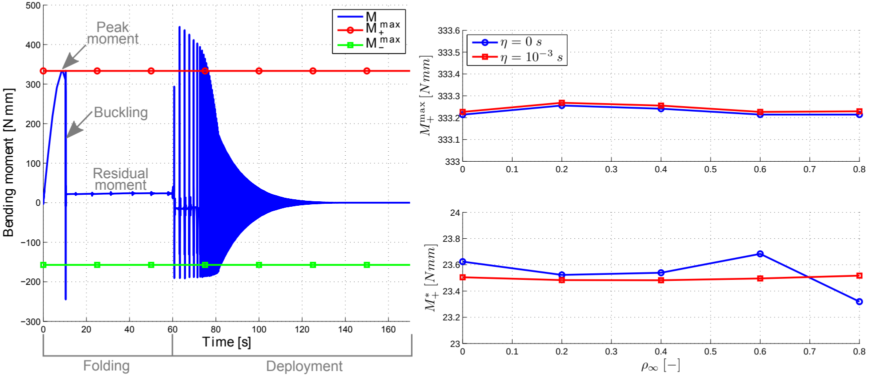
Without structural damping:





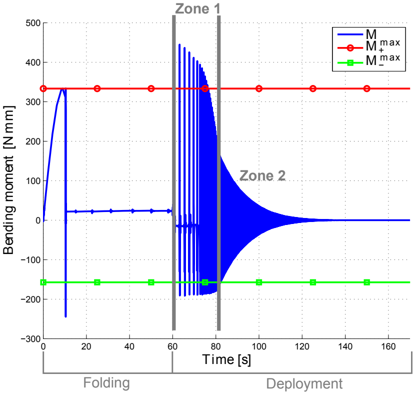
TAPE SPRING - DYNAMIC ANALYSIS

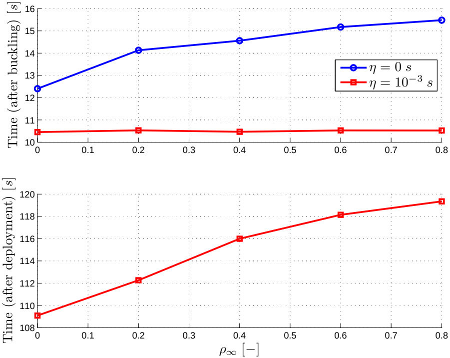
With structural damping:



TAPE SPRING - DYNAMIC ANALYSIS

With structural damping:

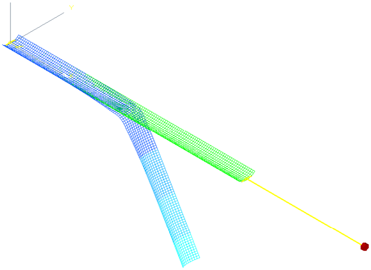




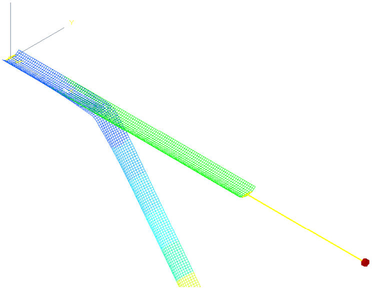
TAPE SPRING - DYNAMIC ANALYSIS

Comparison of the displacements:

With structural damping



Without structural damping



Conclusions

- The two types of damping are required for a valid numerical solution
- Adding some structural damping:
  - reduces the dependence to numerical damping
  - ensures a correct representation of the damping of the oscillations after deployment
  - permits to model the self-locking phenomenon

THANK YOU FOR YOUR ATTENTION

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