

# Viscoelastoplastic cyclic behaviour of sail materials

W.Dib<sup>1</sup>, G.Bles<sup>2</sup>, A.Tourabi<sup>1</sup>

1. Laboratory 3S-R (Soils - Solids - Structures - Risks UMR 5521), Grenoble, France
2. Laboratory LBMS (Brest laboratory of mechanics and systems EA 4325), Brest, France  
[wassim.dib@hmg.inpg.fr](mailto:wassim.dib@hmg.inpg.fr), [guilhem.bles@ensieta.fr](mailto:guilhem.bles@ensieta.fr), [ali.tourabi@hmg.inpg.fr](mailto:ali.tourabi@hmg.inpg.fr)

## Objectives

The aim of this study is to propose constitutive models for woven and laminated sailcloths. The mechanical behavior is studied from small strains to failure (20%), in order to take into account:

- the fabric anisotropy,
- the non-linear elasticity,
- the creep and other viscous phenomena,
- the effect of cyclic loadings on the mechanical behaviour of the sailcloth,
- and, in the longer term, the effect of dynamic loadings.

The proposed constitutive law will be numerically implemented in the FEM (code Abaqus) in order to predict the flying shape and particularly the stresses in the panels and the seams.

## Fabric sample and tensile experimental device

Two sail fabrics were studied; “Dacron 300 SF HTM” and “Dacron 300 SF HTP plus” (Dimension-polyant). These materials are woven with polyester fibers. Their mass densities are respectively  $m_s = 312 \text{ g/m}^2$  and  $m_s = 298 \text{ g/m}^2$ . The sample is clamped to the testing machine by a pair of swivel jaws, able to perform off-axis tensile tests. The length of the sample is  $L=300 \text{ mm}$  and the width is  $W = 50 \text{ mm}$ . The sample axial strain is measured locally by an optical system, with the help of a CCD camera. The optical system tracks the targets and trajectories are recorded during the test (Fig. 1).

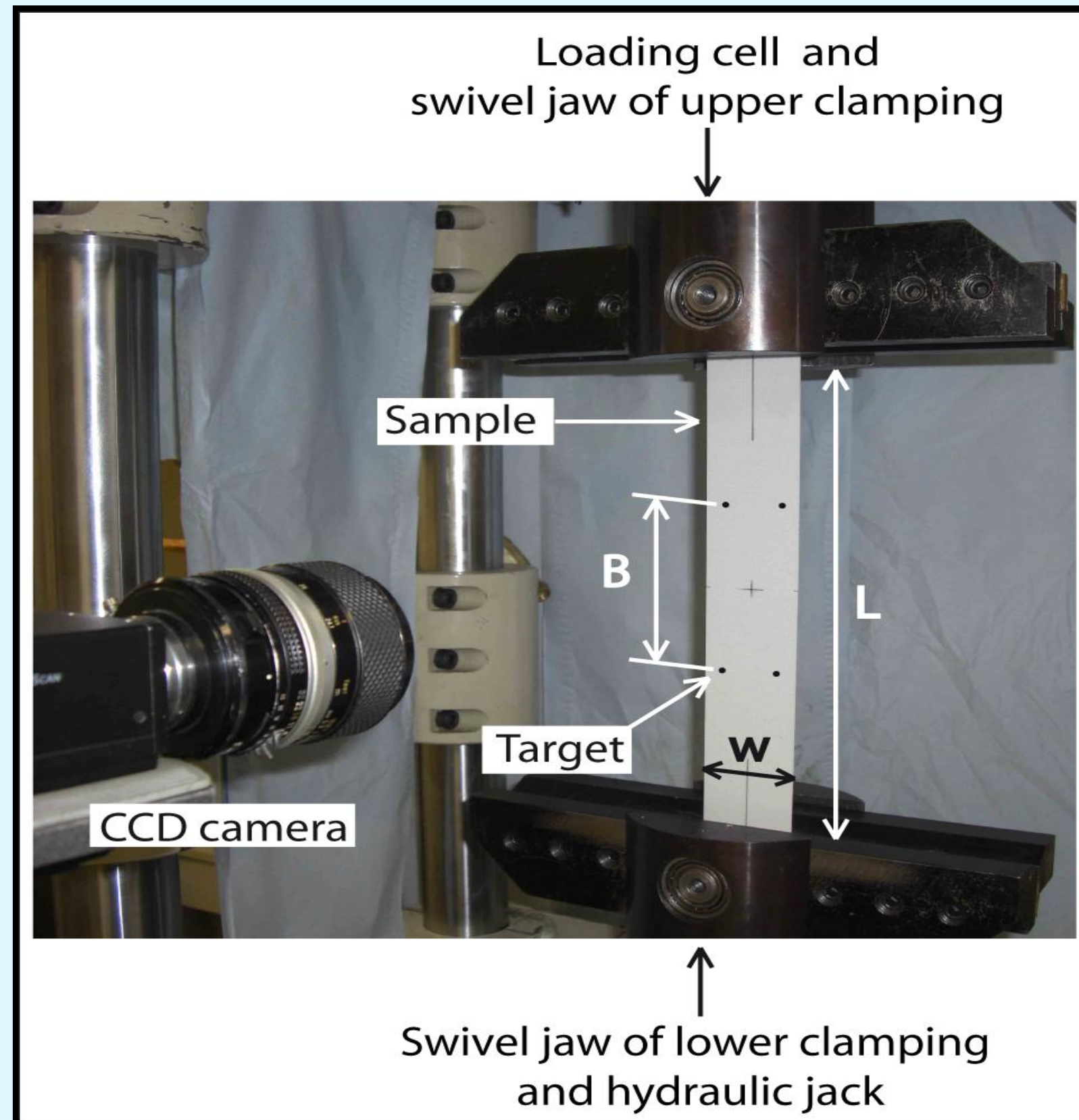


Figure 1: Sample attached to hydraulic testing machine.

## Mechanical properties characterization

Monotonous tensile tests at constant strain rates were performed with “Dacron 300 SF HTM”, in warp and fill directions. During these tests, the strain rate was maintained constant at  $\dot{D}=10^{-3} \text{ s}^{-1}$ :

### In the warp direction

Young Modulus =  $1727 \pm 28 \text{ J/g}$   
Poisson's ratio =  $0.020 \pm 0.0004$   
Failure stress =  $122 \pm 11 \text{ J/g}$   
Failure strain =  $0.174 \pm 0.015$

### In the fill direction

Young Modulus =  $2850 \pm 130 \text{ J/g}$   
Poisson's ratio =  $0.046 \pm 0.0005$   
Failure stress =  $147 \pm 12 \text{ J/g}$   
Failure strain =  $0.177 \pm 0.020$

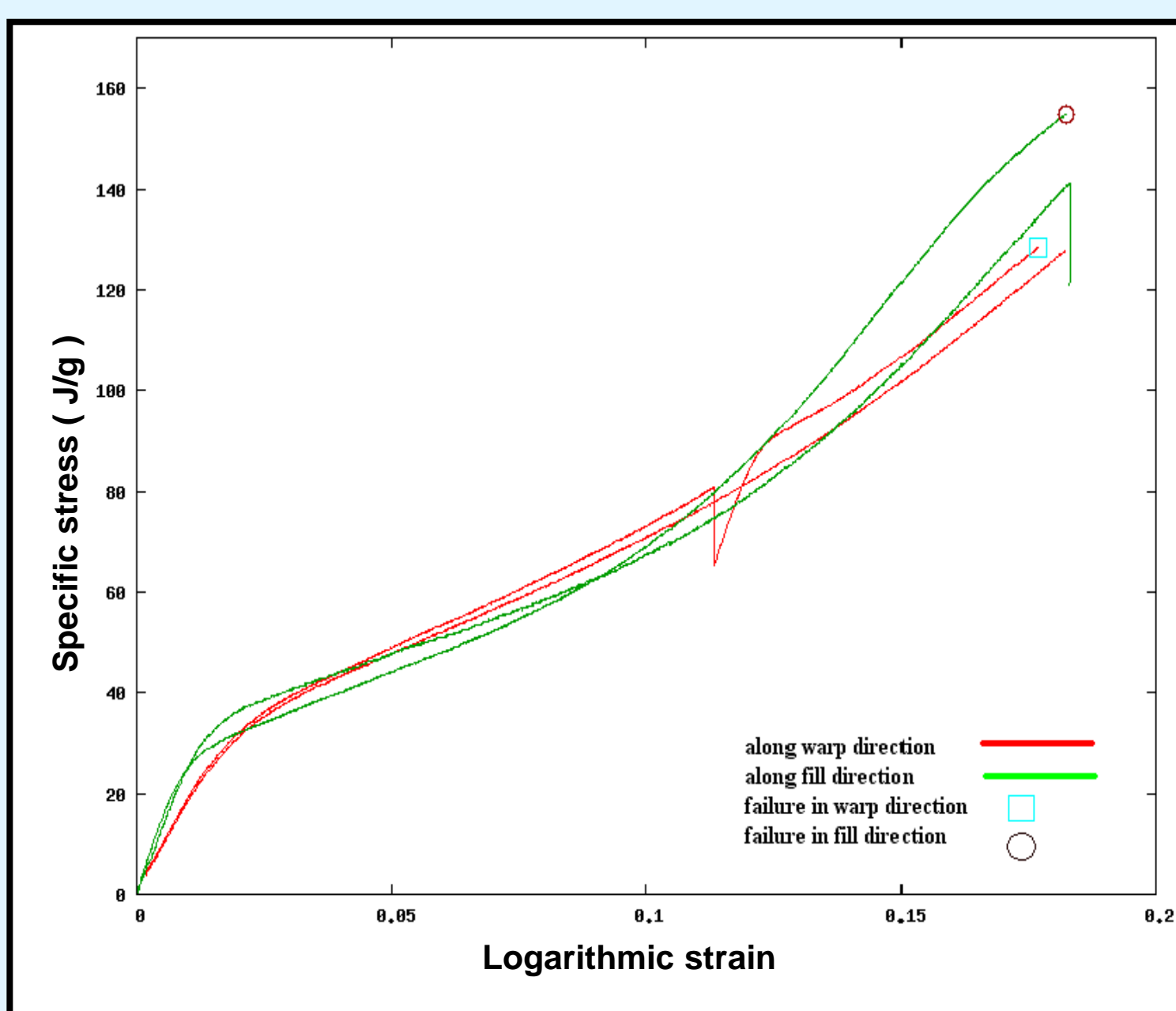


Figure 2: Results of monotonous tensile tests.

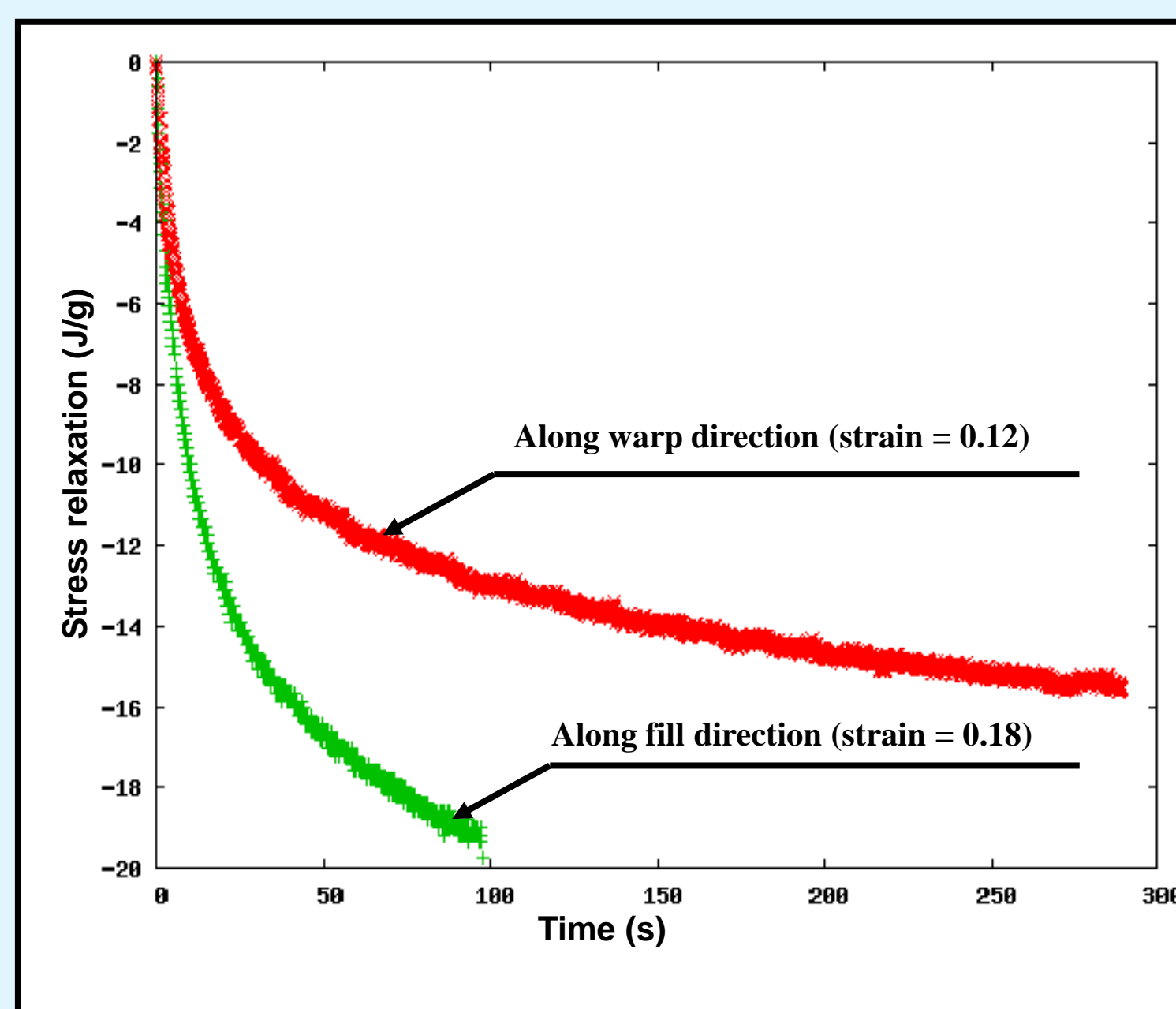


Figure 3: Time evolution of stress relaxations ab and cd of figure 2.

## Linear viscoelastic model (first step)

In the isotropic biaxial case the constitutive law is defined by the following relations :

$$\bar{\sigma} = \bar{\sigma}_v + \bar{\sigma}_e$$

$$\bar{\sigma}_v + \frac{\overset{\circ}{rp}}{\theta_v} \bar{\sigma}_v = \lambda_v \cdot \text{Tr}(\bar{D}) \cdot \bar{I} + 2\mu_v \cdot \bar{D}$$

$$\bar{\sigma}_e = \lambda_e \cdot \text{Tr}(\bar{LnV}) \cdot \bar{I} + 2\mu_e \cdot \bar{LnV}$$

Where  $\bar{LnV}$  is the logarithmic eulerian strain and the time derivative  $\frac{\overset{\circ}{rp}}{A}$  is the Green - Naghdi objective rate.

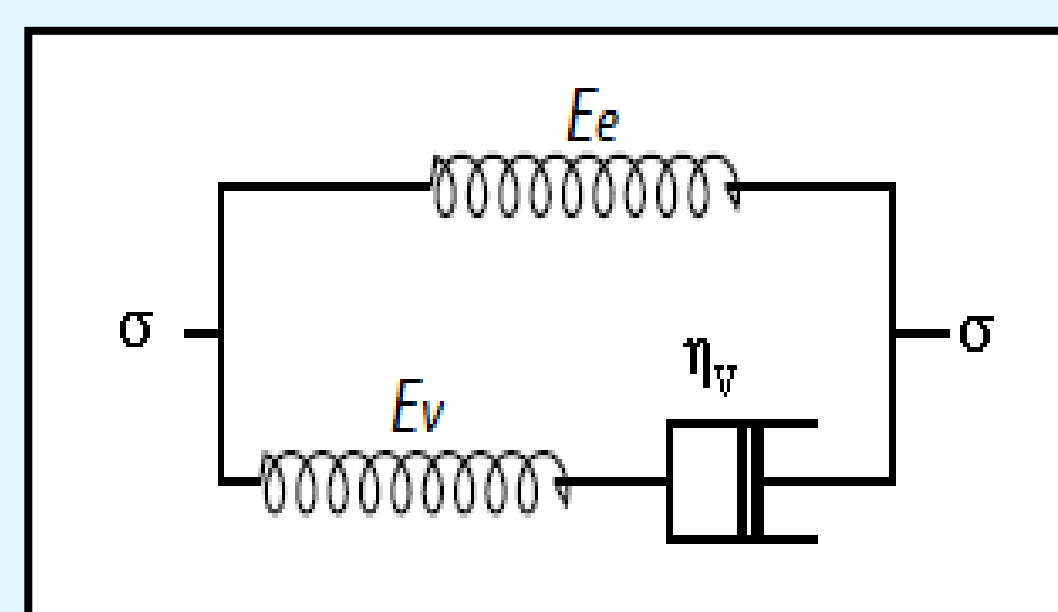


Figure 4: The Zener model.

## Viscoelastic numerical simulation of a sail

The mechanical behaviour of a flat sail was simulated (Abaqus FEA software). We assumed that the sail is made of an isotropic “Dacron 300 SF HTM”. The model parameters were identified using the tensile tests along the warp direction :

- Young Modulus of viscous stress =  $1413 \text{ J/g}$
- Poisson's ratio of viscous stress = 0.02
- Young Modulus of elastic stress =  $570 \text{ J/g}$
- Poisson's ratio of elastic stress = 0.02
- Relaxation time of viscous stress = 11 s.

544 linear membrane elements (M3D3: 3-node triangles). The nodes of the luff and the clew node are pinned. A homogeneous pressure is applied on the sail. Nonlinearities due to large deflections are taken into account.

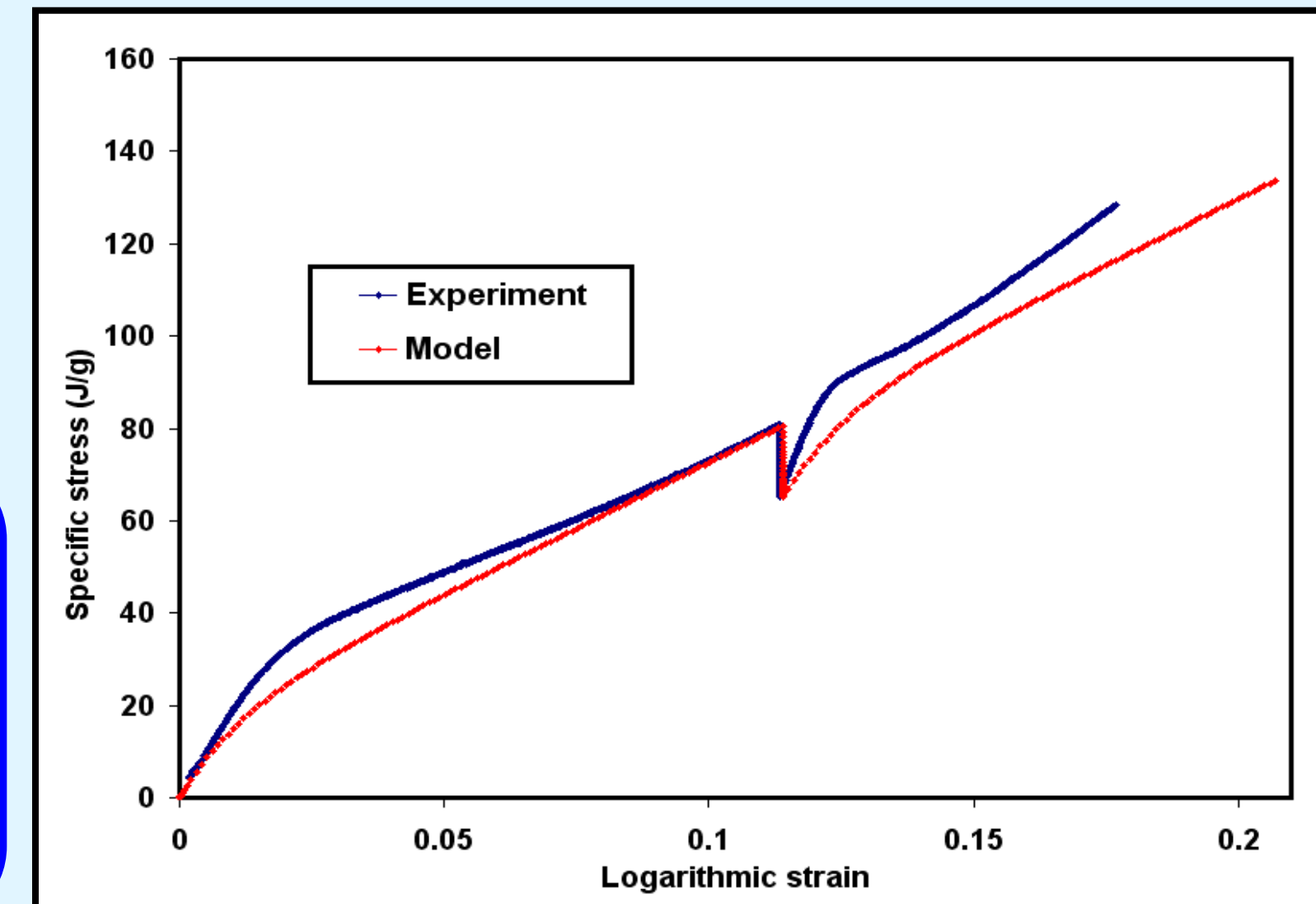


Figure 5: Tensile experimental results (warp direction) and its numerical simulation.

The first phase of loading corresponds to a constant pressure  $P=80 \text{ Pa}$ . The second phase of the load ( $P=150 \text{ Pa}$ ) is then applied. The span of rising in pressure between the first and second phase is 2 seconds. Pressure 150 Pa is maintained constant during 2 minutes in the last phase of loading (creep).

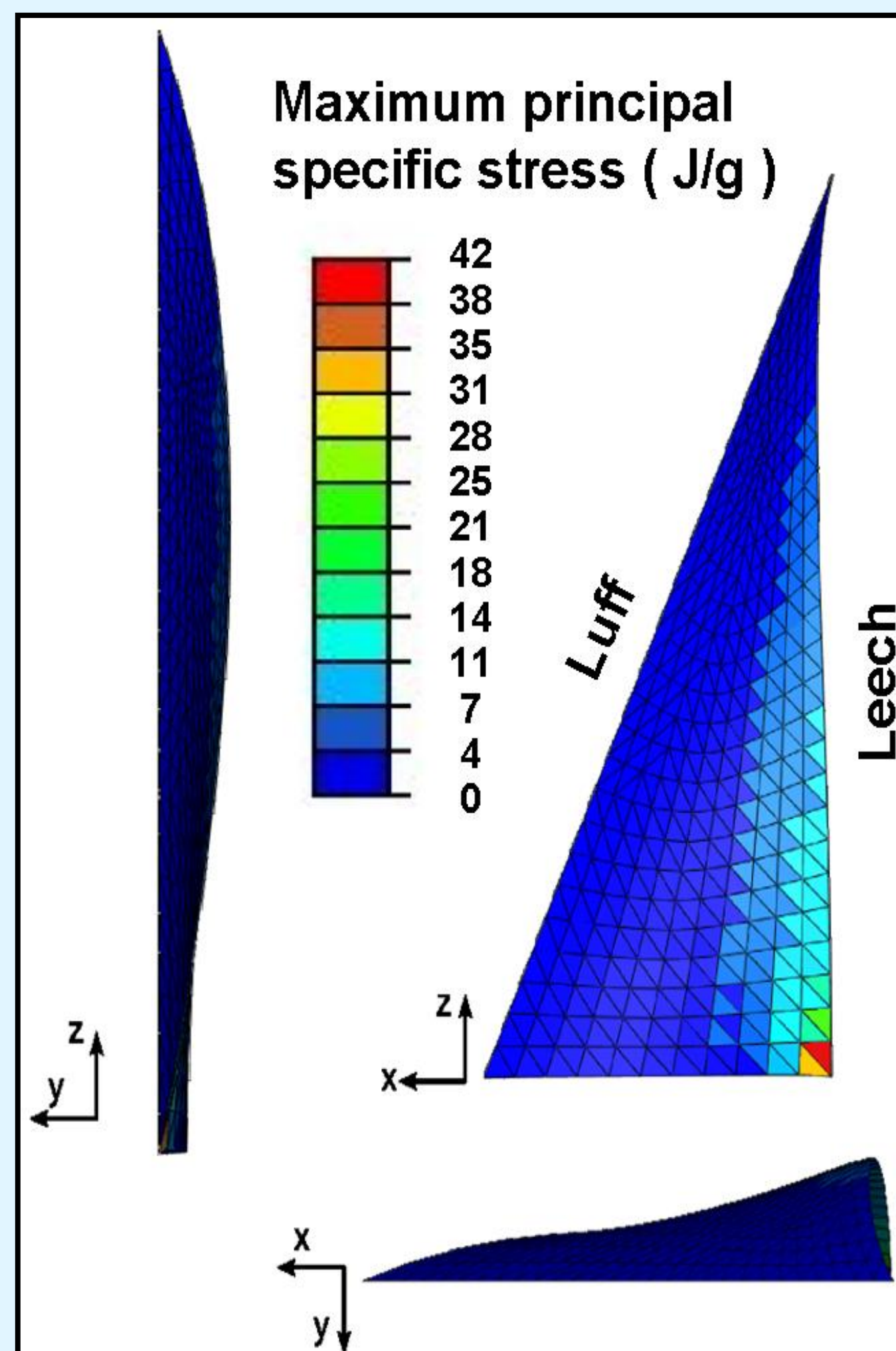


Figure 6: Meshed flat sail geometry and maximum principal specific stress.  $P=150 \text{ Pa}$ , sail height = 8 m.

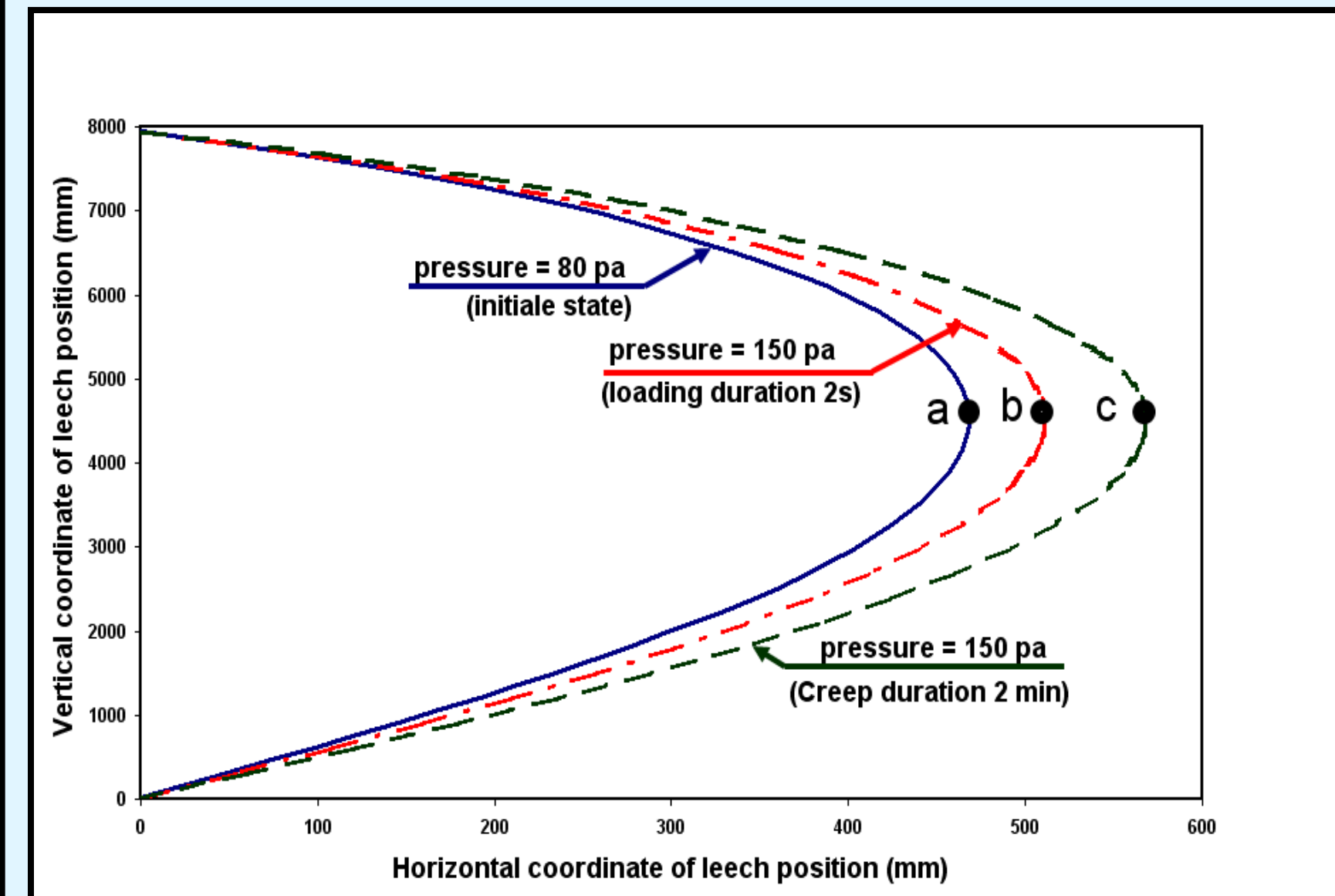


Figure 7: Projection on plane y-z of the leech positions.

## Monotonous and cyclic creep tensile tests

Two tensile tests interrupted by creep periods were conducted on fabric “Dacron 300 SF HTP plus”. The stress rate was controlled and maintained constant at  $671 \text{ J/(kg.s)}$ . The loading and unloading processes were broken by creep periods, during which the stress is constant. The duration of each period was one hour.

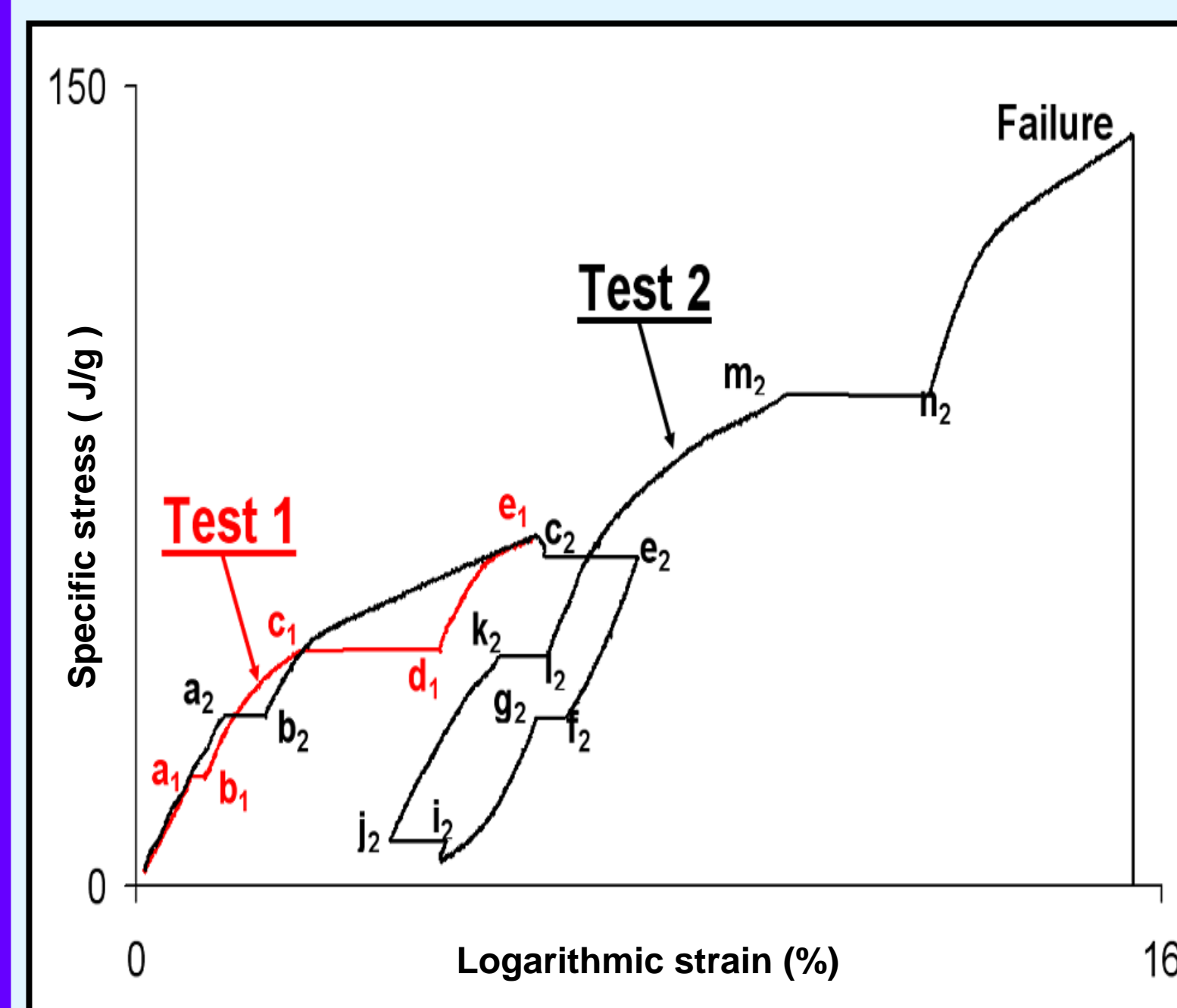


Figure 8: Results of monotonous and cyclic tensile tests with creep periods.

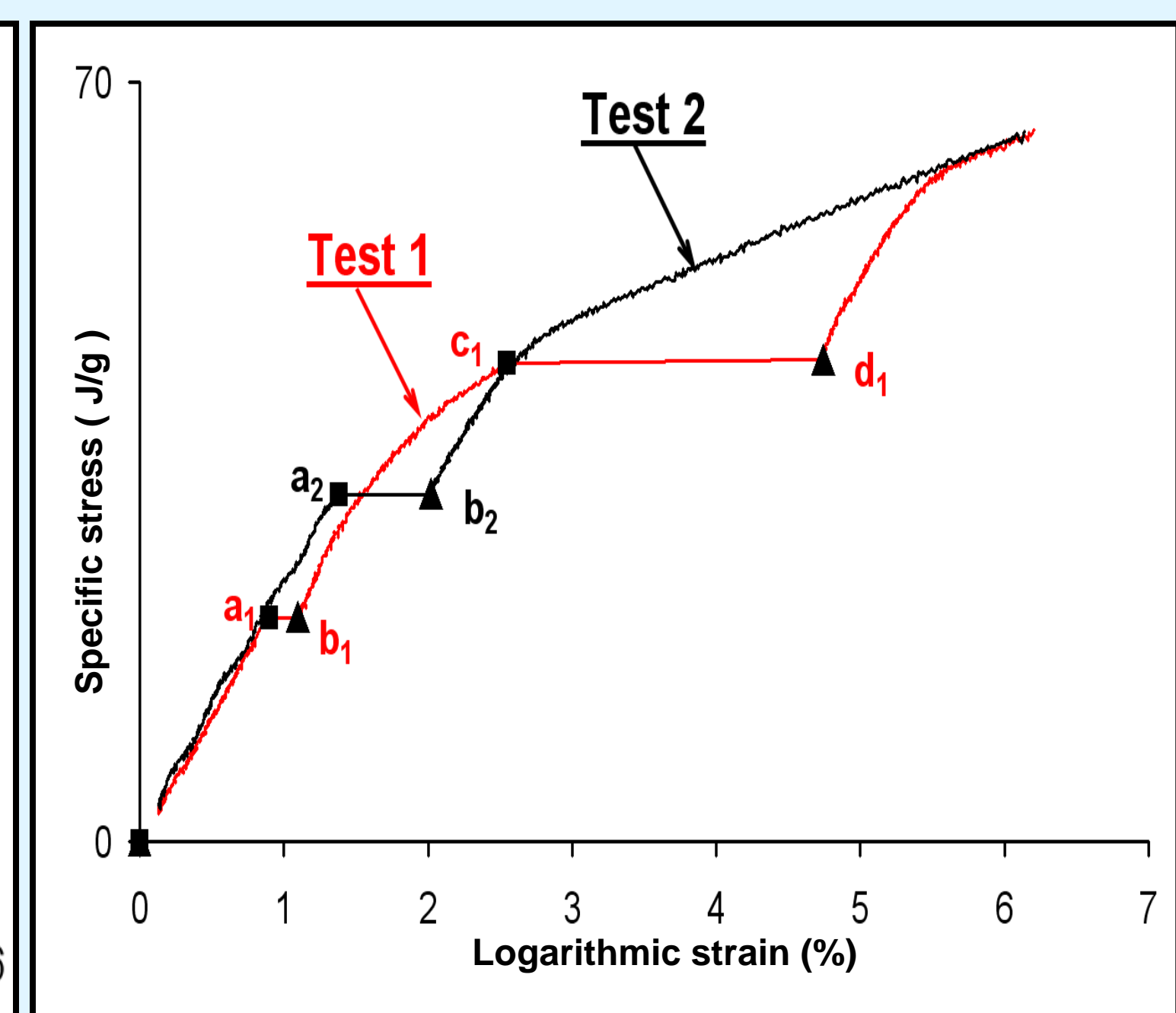


Figure 9: Zoom of figure 8 between (0 to 7 %) of logarithmic strain.

The creep phenomena are significant even at small strain (from 1% to 3%).

## Conclusion

A structural analysis of a flat sail is proposed using the finite element method. This study takes into account the viscous phenomena. The results underline the importance of viscosity or creep of a Dacron woven fabric, which has a significant effect on the structural behaviour of the sail, even at small strain.

## Future plans

To enhance the constitutive model to :

- Non- linear elasticity,
- Anisotropy,
- Cyclic behaviour.

To perform a fluid- structure interaction with the enhanced model.