



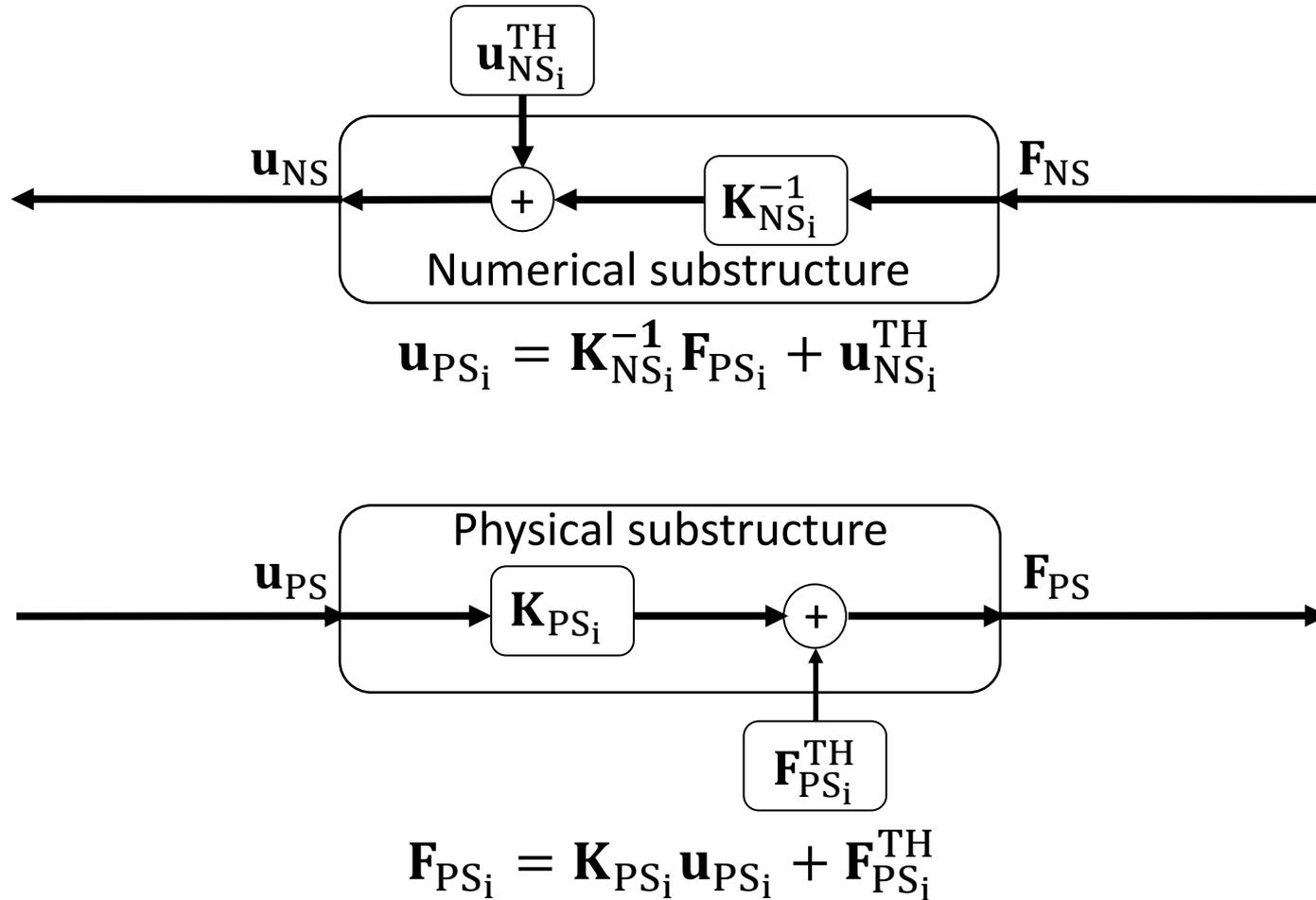
PI control in HFT

E. Mergny, G. Drion & J.M. Franssen

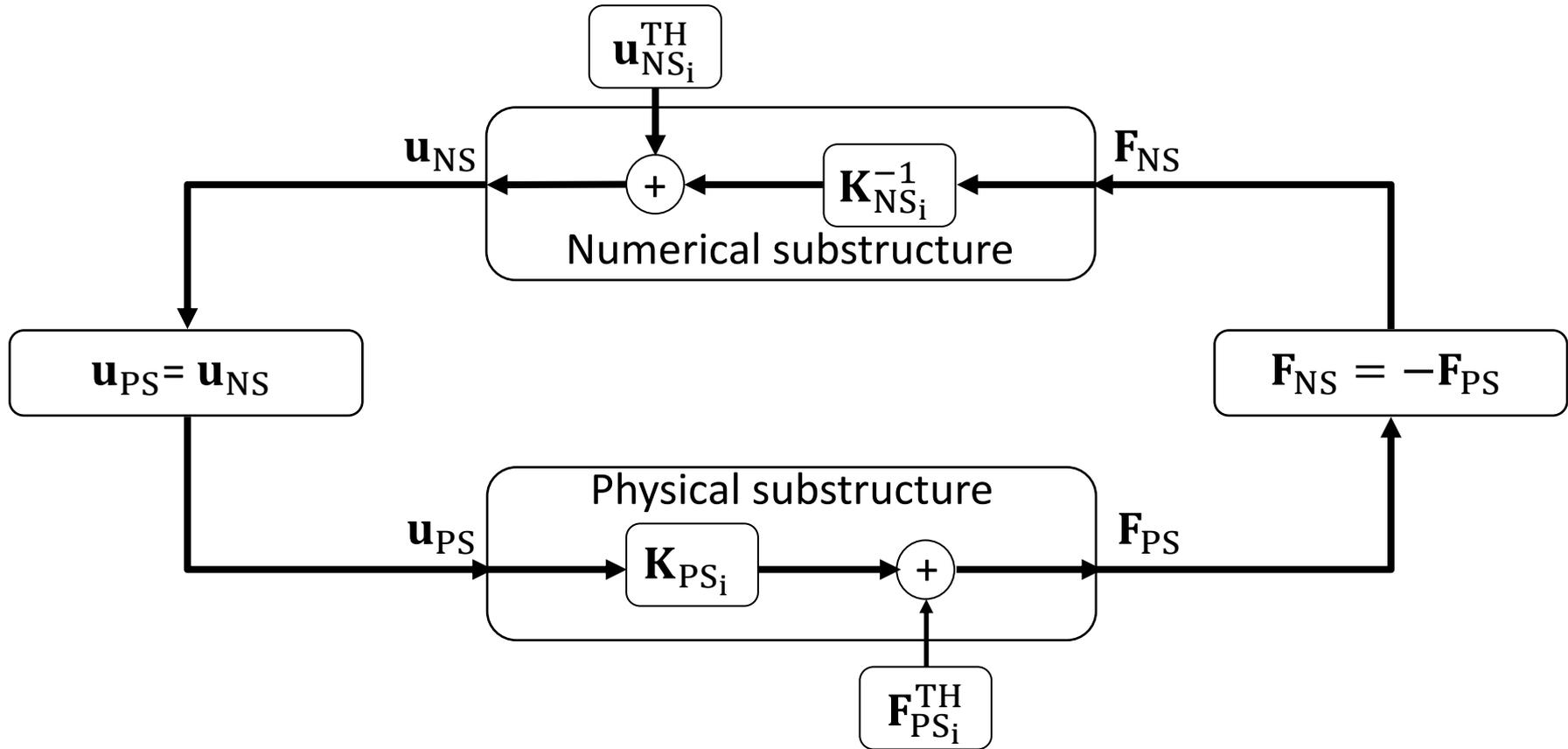
Elke Mergny

Liege University

HYBRID FIRE TESTING

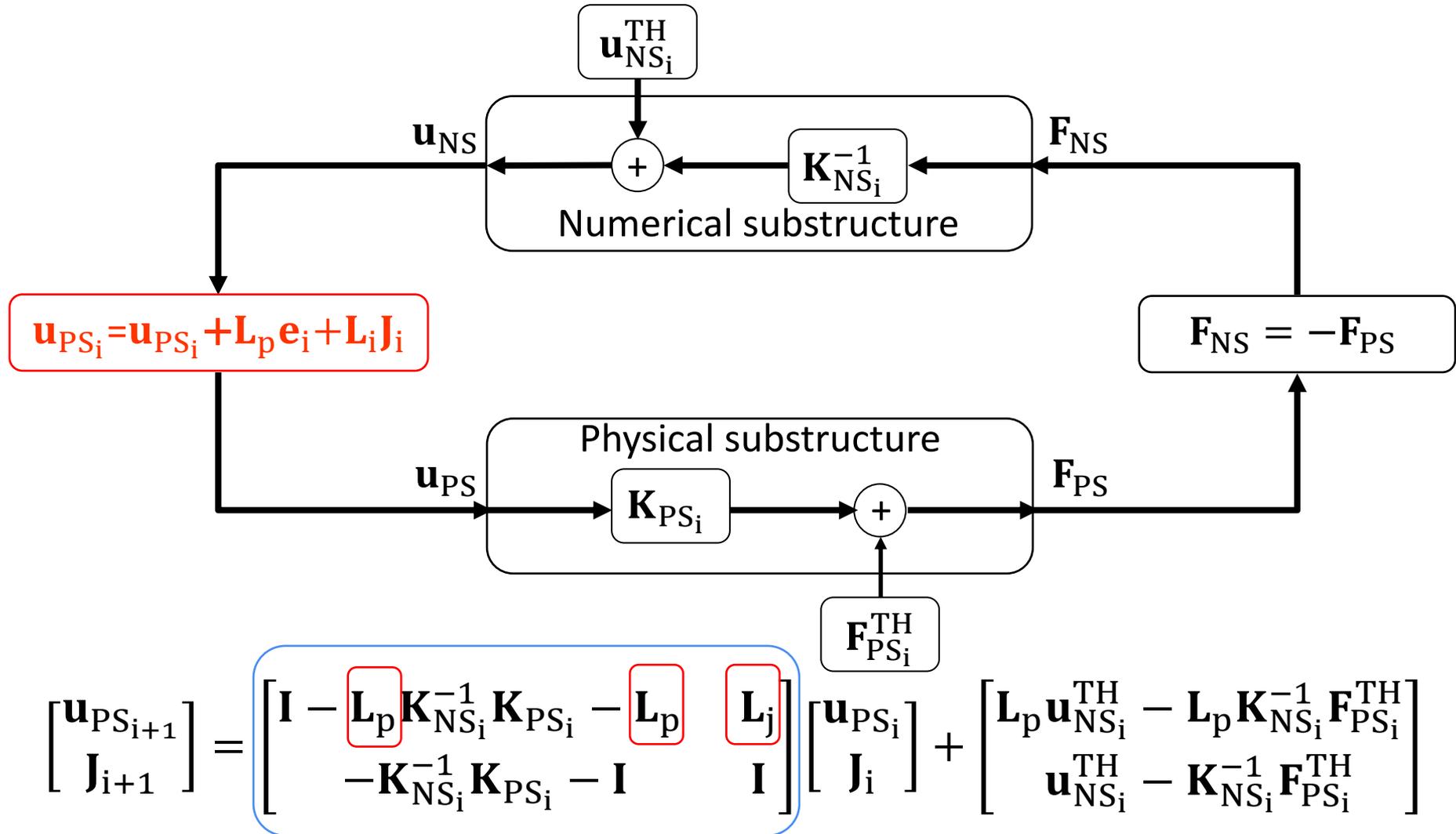


HYBRID FIRE TESTING



$$\mathbf{u}_{PS_{i+1}} = -\mathbf{K}_{NS_i}^{-1} \mathbf{K}_{PS_i} \mathbf{u}_{PS_i} + \mathbf{u}_{NS_i}^{TH} - \mathbf{K}_{NS_i}^{-1} \mathbf{F}_{PS_i}^{TH}$$

PI-CONTROL

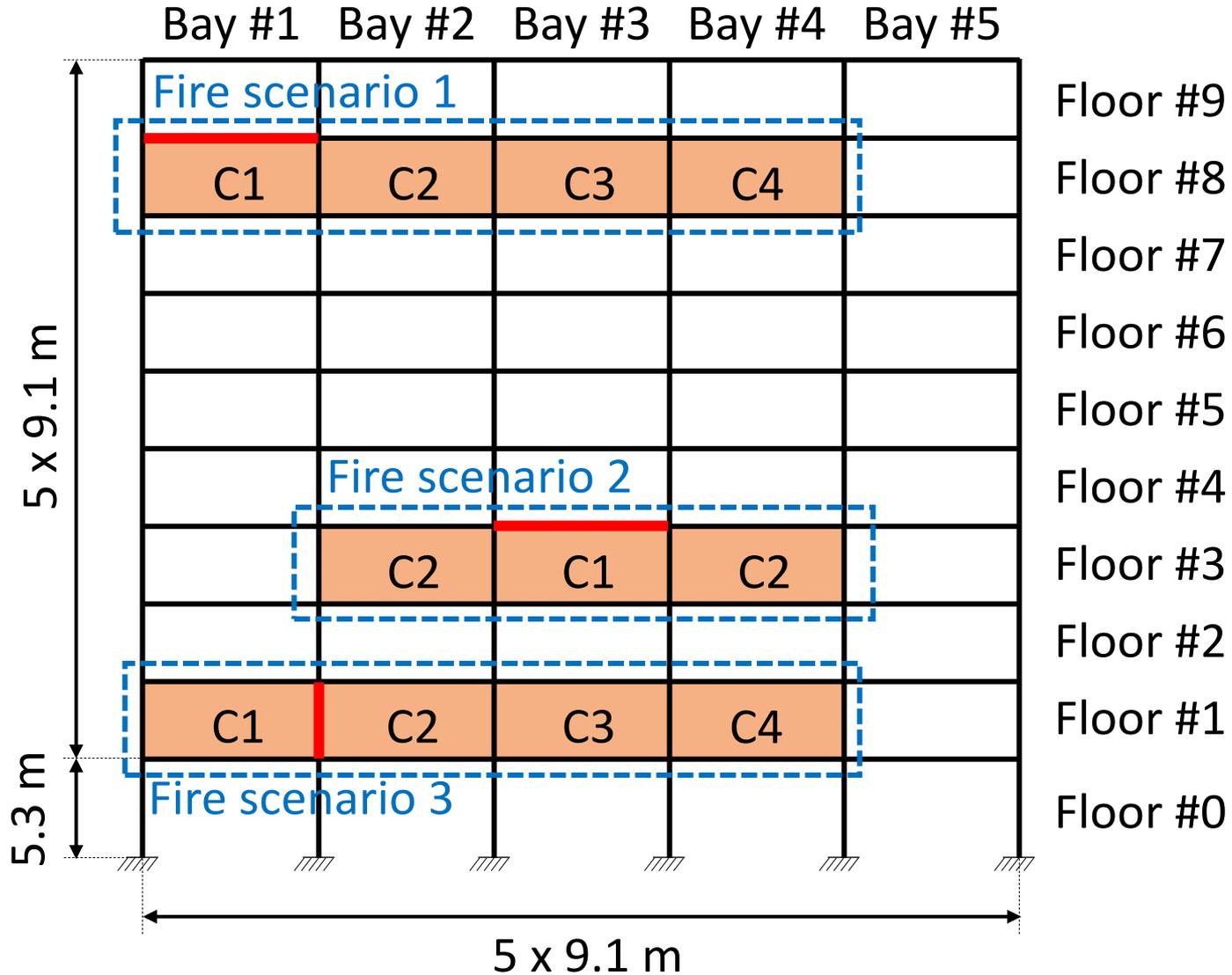


PI-CONTROL

$$\begin{bmatrix} \mathbf{u}_{PS_{i+1}} \\ \mathbf{J}_{i+1} \end{bmatrix} = \begin{bmatrix} \mathbf{I} - \mathbf{L}_p \mathbf{K}_{NS_i}^{-1} \mathbf{K}_{PS_i} - \mathbf{L}_p & \mathbf{L}_j \\ -\mathbf{K}_{NS_i}^{-1} \mathbf{K}_{PS_i} - \mathbf{I} & \mathbf{I} \end{bmatrix} \begin{bmatrix} \mathbf{u}_{PS_i} \\ \mathbf{J}_i \end{bmatrix} + \begin{bmatrix} \mathbf{L}_p \mathbf{u}_{NS_i}^{TH} - \mathbf{L}_p \mathbf{K}_{NS_i}^{-1} \mathbf{F}_{PS_i}^{TH} \\ \mathbf{u}_{NS_i}^{TH} - \mathbf{K}_{NS_i}^{-1} \mathbf{F}_{PS_i}^{TH} \end{bmatrix}$$

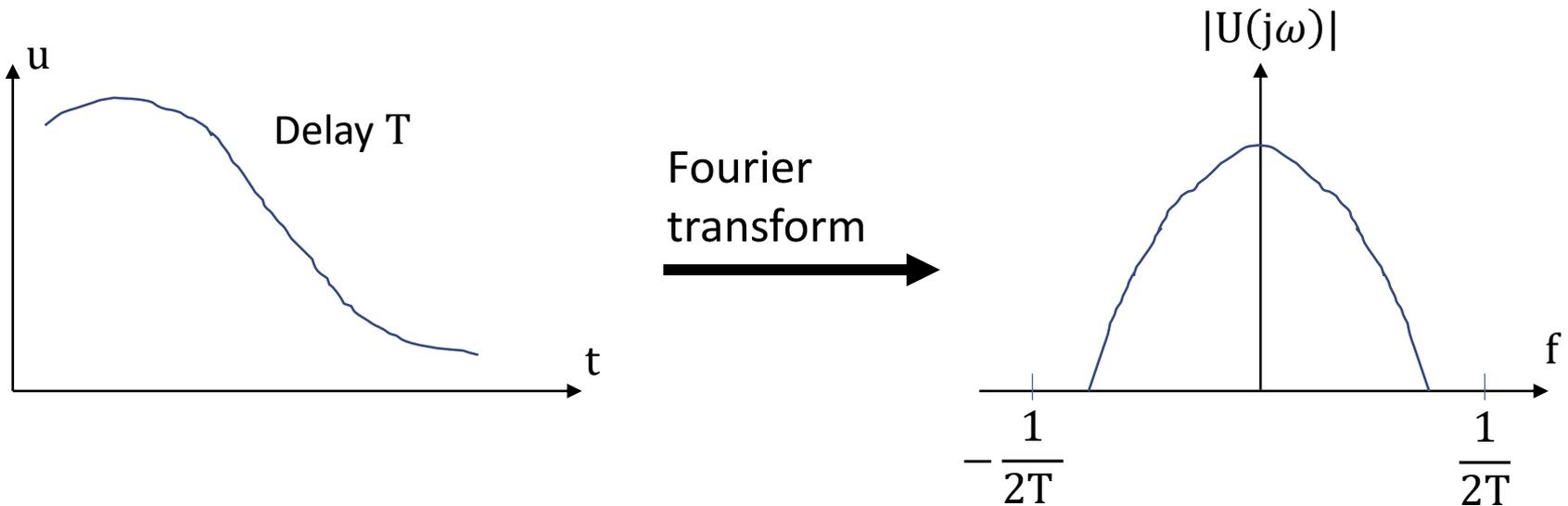
- Delay = Sampling time \rightarrow Shannon Nyquist theorem
- Error of measurement
- Estimation of the stiffness
$$\mathbf{K}_{PS_0}^{EST} \rightarrow \mathbf{K}_{PS_0} (1 + u)$$
- Variation of the stiffness

VIRTUAL HYBRID FIRE TESTING



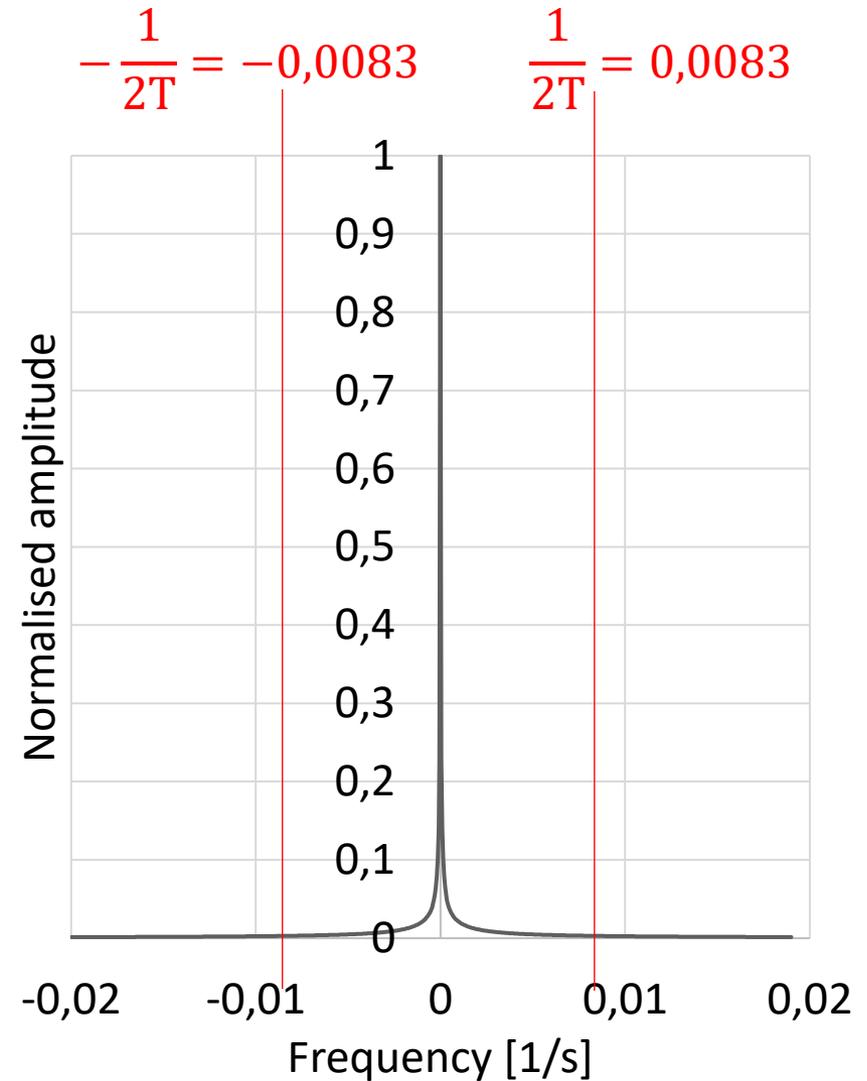
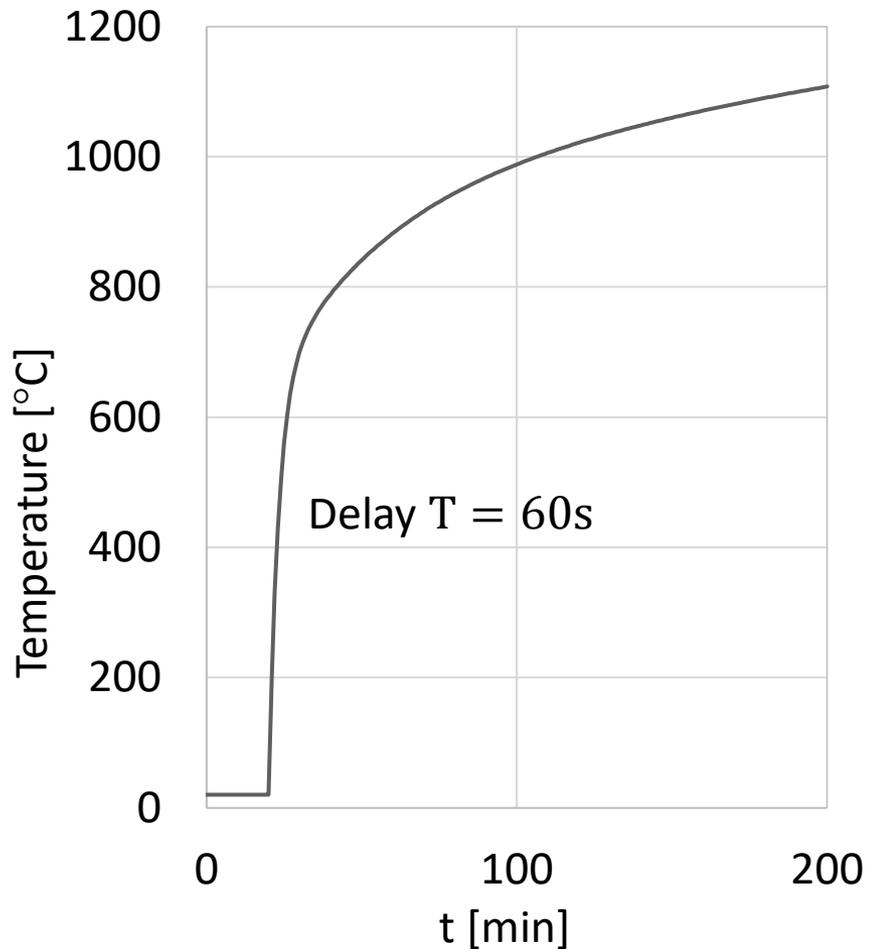
DELAY

- Maximum delay = 60 s
- Shannon Nyquist theorem



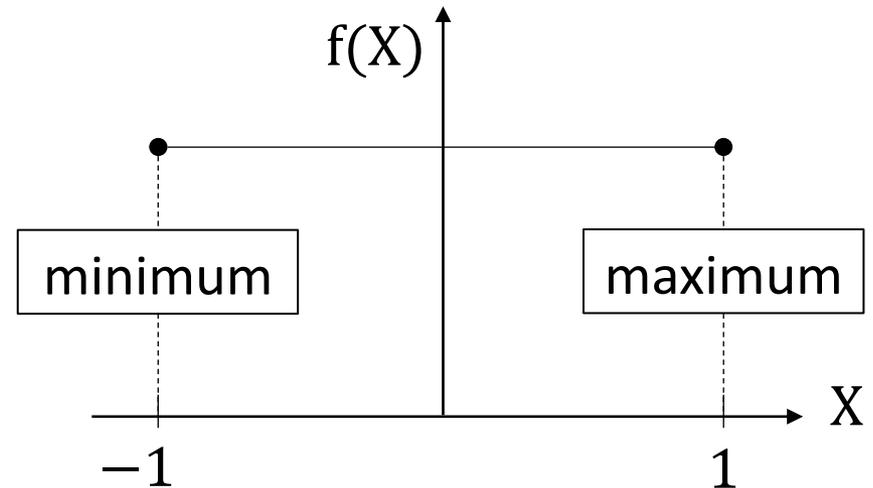
DELAY

Shannon Nyquist theorem



ERRORS

$$M = M_{\text{real}} + e_r \times X$$



- Application of displacements

$$e_{r,\text{axial dipl}} = 0.000002 \text{ [mm]}$$

$$e_{r,\text{rotation}} = 0.00005 \text{ [rad]}$$

- Measure of forces

$$e_{r,\text{force}} = 5 \text{ [N]}$$

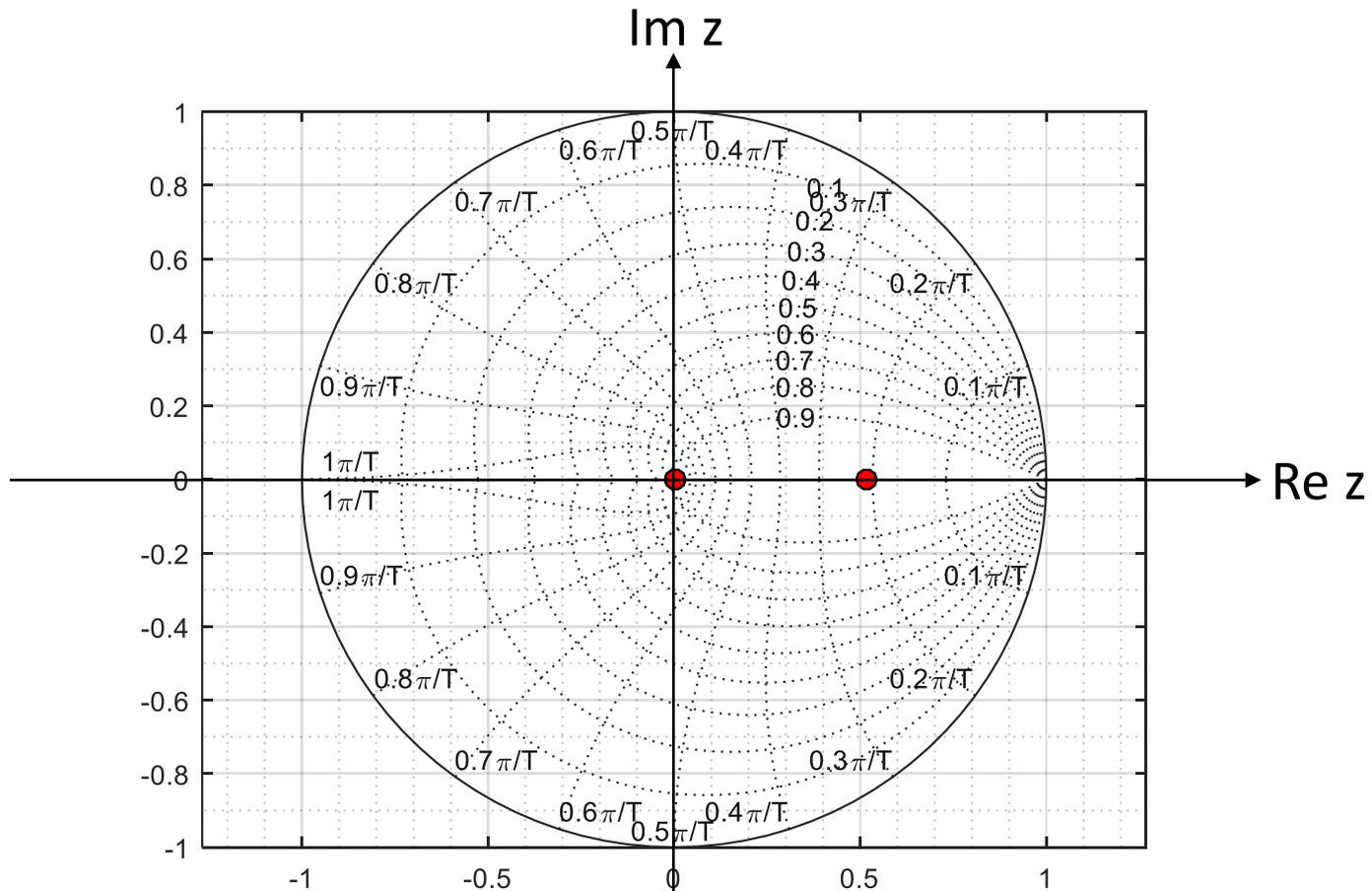
INITIAL STIFFNESS

$$\mathbf{K}_{NS_0} = 10^4 \begin{bmatrix} 80,775 & 4,073 & 6,080 \\ 4,073 & 623,333 & -333,333 \\ 6,080 & -333,333 & 7667,667 \end{bmatrix} [\text{m, N, rad}]$$

$$\mathbf{K}_{PS_0} = 10^4 \begin{bmatrix} EA/L & 0 & 0 \\ 0 & 4EI/L & 2EI/L \\ 0 & 2EI/L & 4EI/L \end{bmatrix} (1 + u) \Rightarrow u = [-0,5; 0,5]$$
$$= 10^4 \begin{bmatrix} 9663,077 & 0 & 0 \\ 0 & 762,277 & 381,138 \\ 0 & 381,138 & 762,277 \end{bmatrix} (1 + u) [\text{m, N, rad}]$$

DESIGN OF THE CONTROLLER

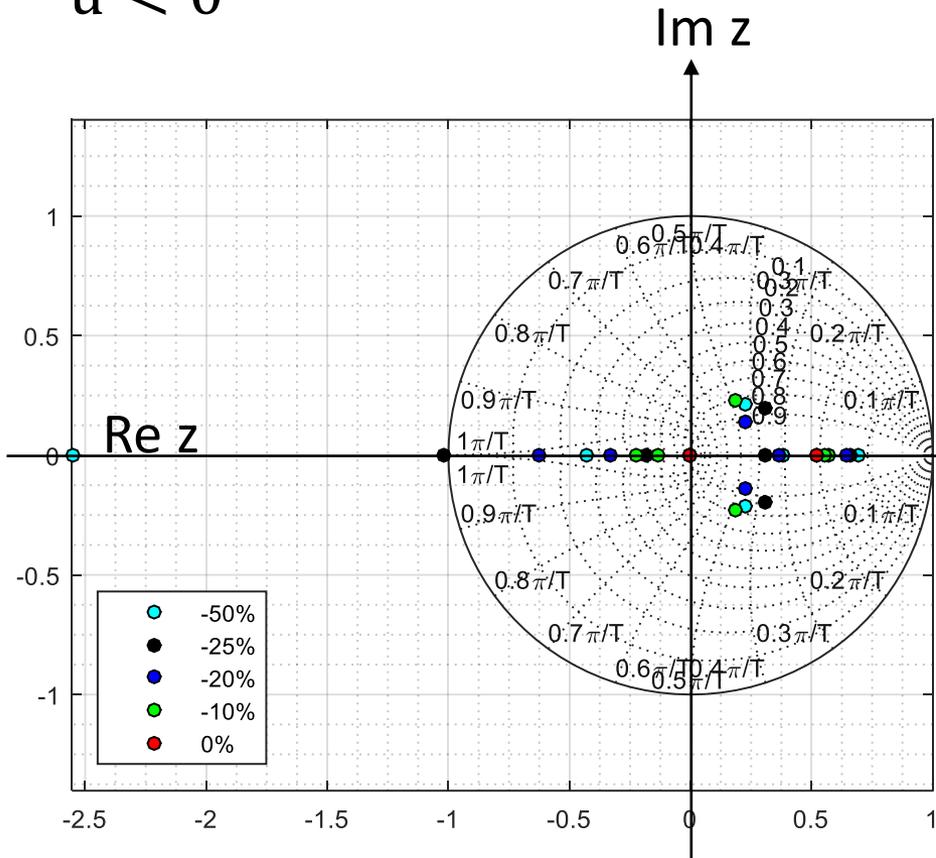
$$T_s = \frac{4T}{|\ln(\lambda)|\zeta} \rightarrow \lambda = \exp\left(-\frac{4 \times 60}{360}\right) = 0,5134$$



OVERESTIMATION OF $K_{PS} - u > 0$

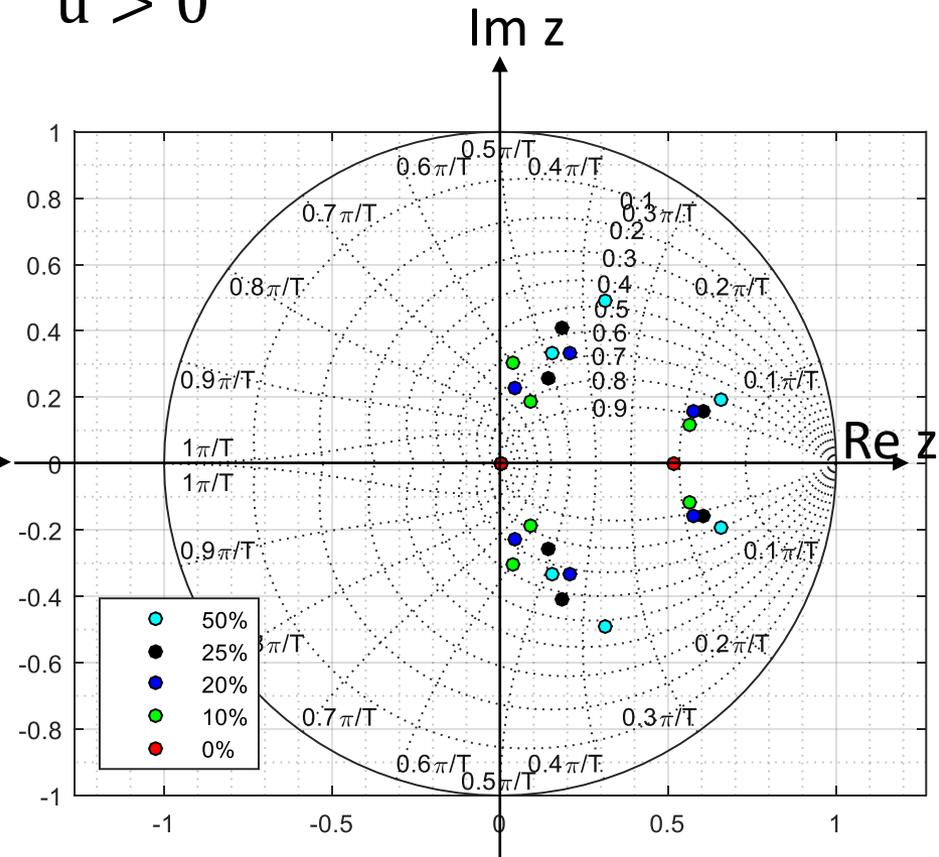
$$K_{PS_0}(1 + u)$$

$$u < 0$$

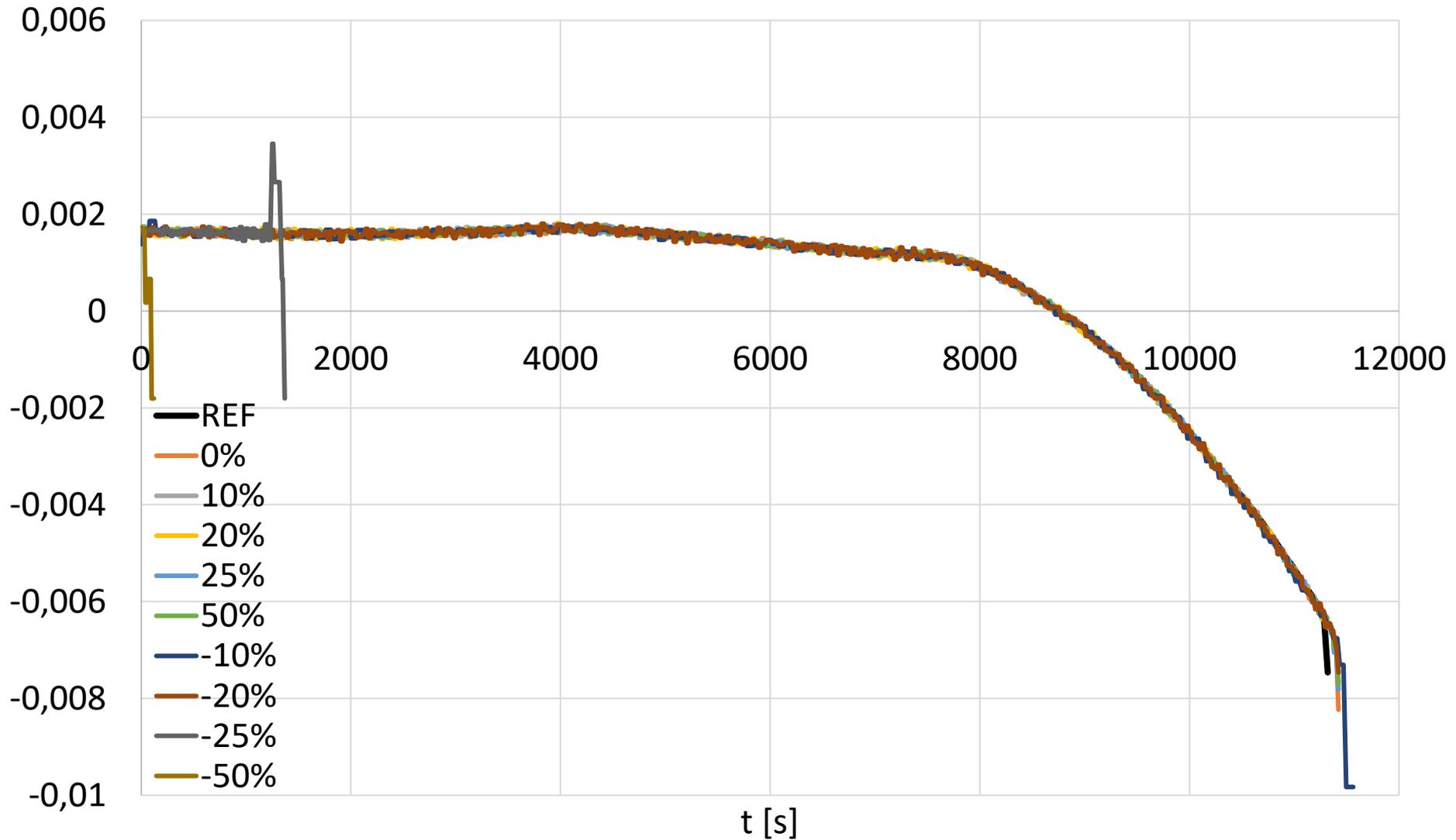


$$K_{PS_0}(1 + u)$$

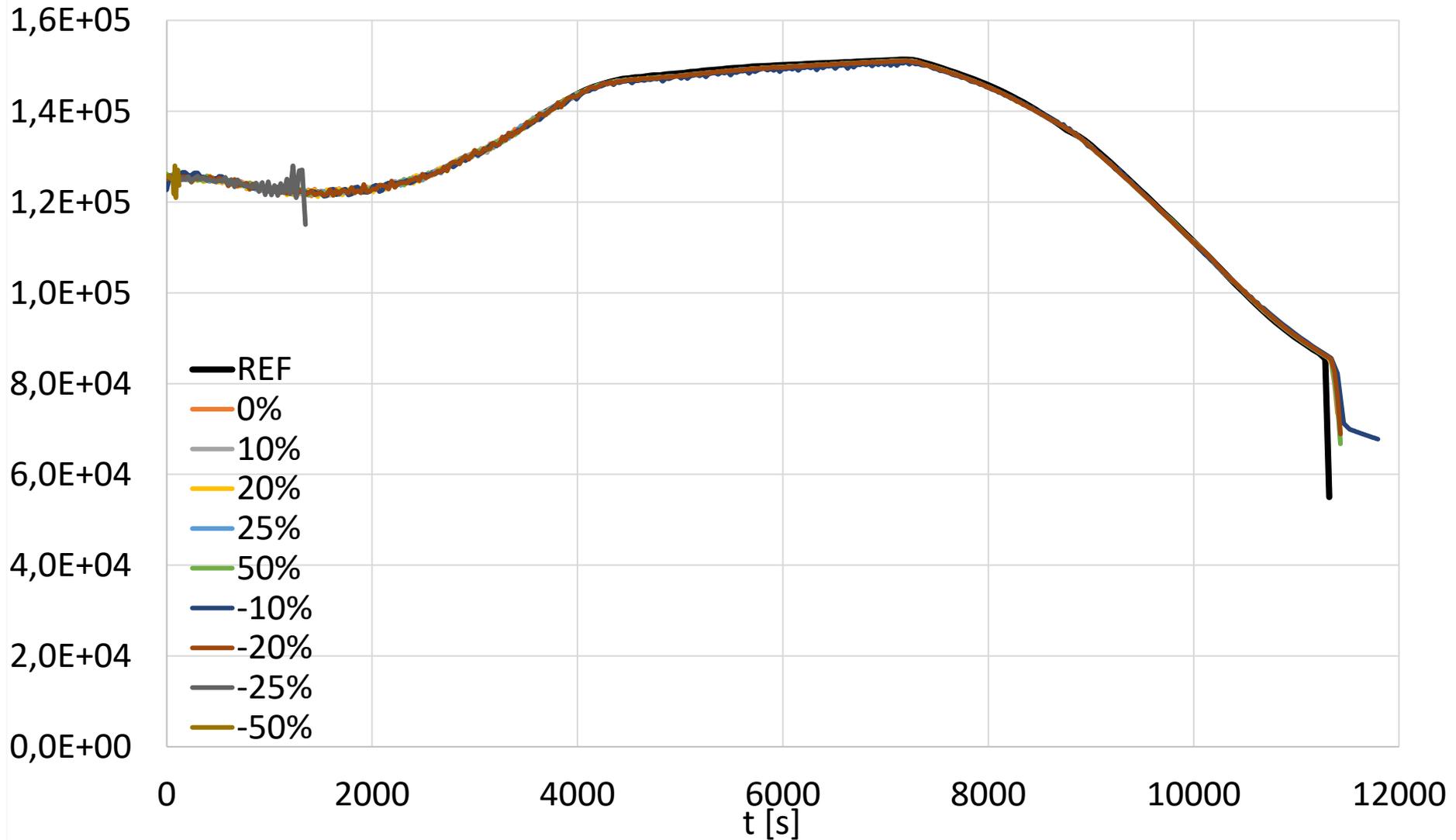
$$u > 0$$



RESULTS - RIGHT ROTATION [rad]



RESULTS - RIGHT BENDING MOMENT [rad]



CONCLUSIONS

- Robust methodology in case of large delays and in case of overestimation of the physical stiffness
- Sensitive to underestimation