LIÈGE université

UNIVERSIDAD DE LA FRONTERA

Efficient thermo-mechanical modelling of cyclic loading with Chaboche type constitutive law coupled with damage

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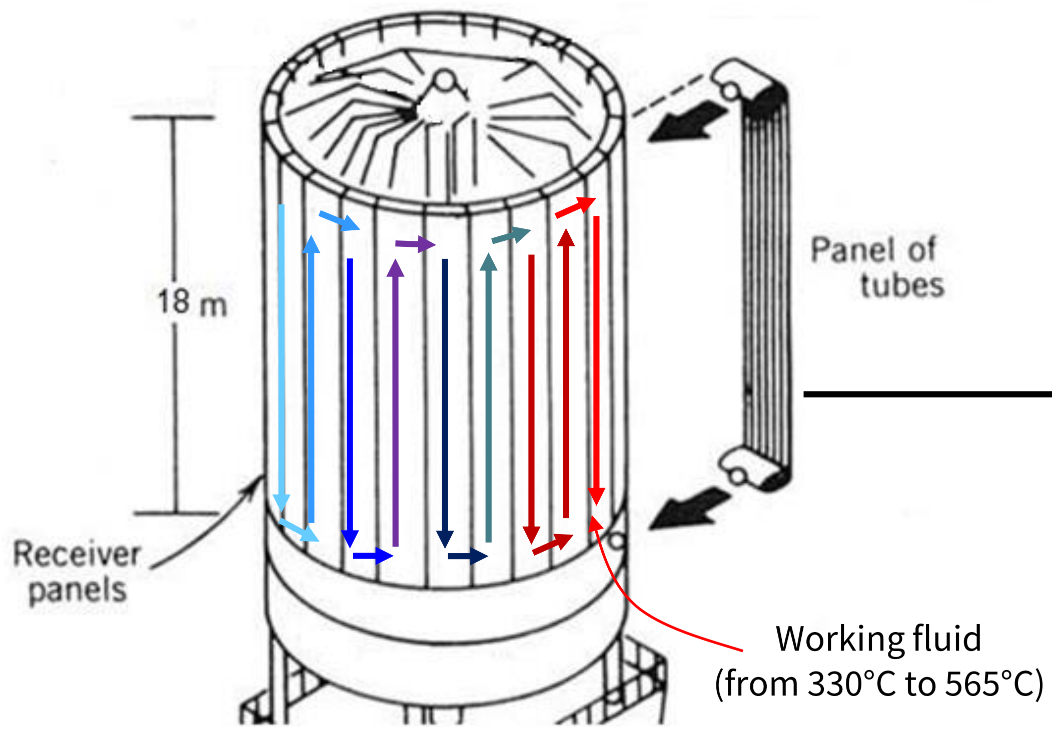
Context: Solar power plant

Solar receivers: extreme thermo-mechanical conditions

Khi Solar One power plant (South Africa)

Context: Solar receiver



Tube:
Ø 50 mm
t=1.5 mm

Solar receiver

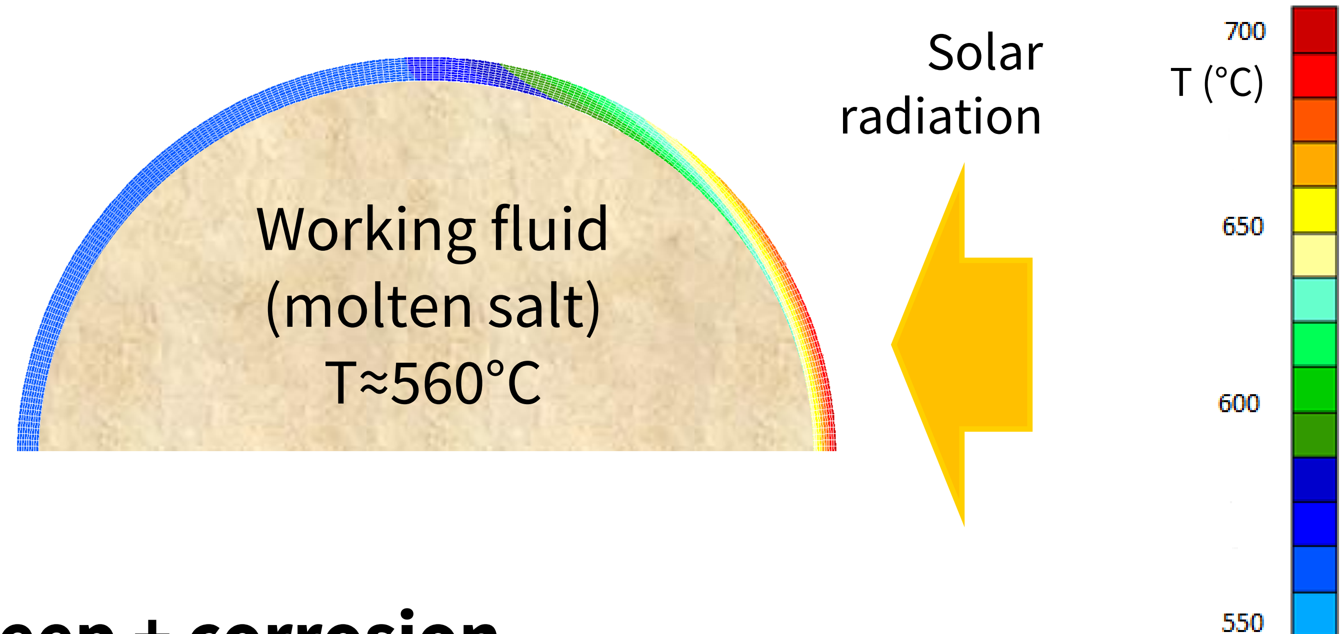
(source : W.B.Stine, R.W.Harrigan, Solar Energy Systems Design)

Panel of tubes manufactured from nickel alloy sheet (Haynes 230)

(source : CMI Solar)

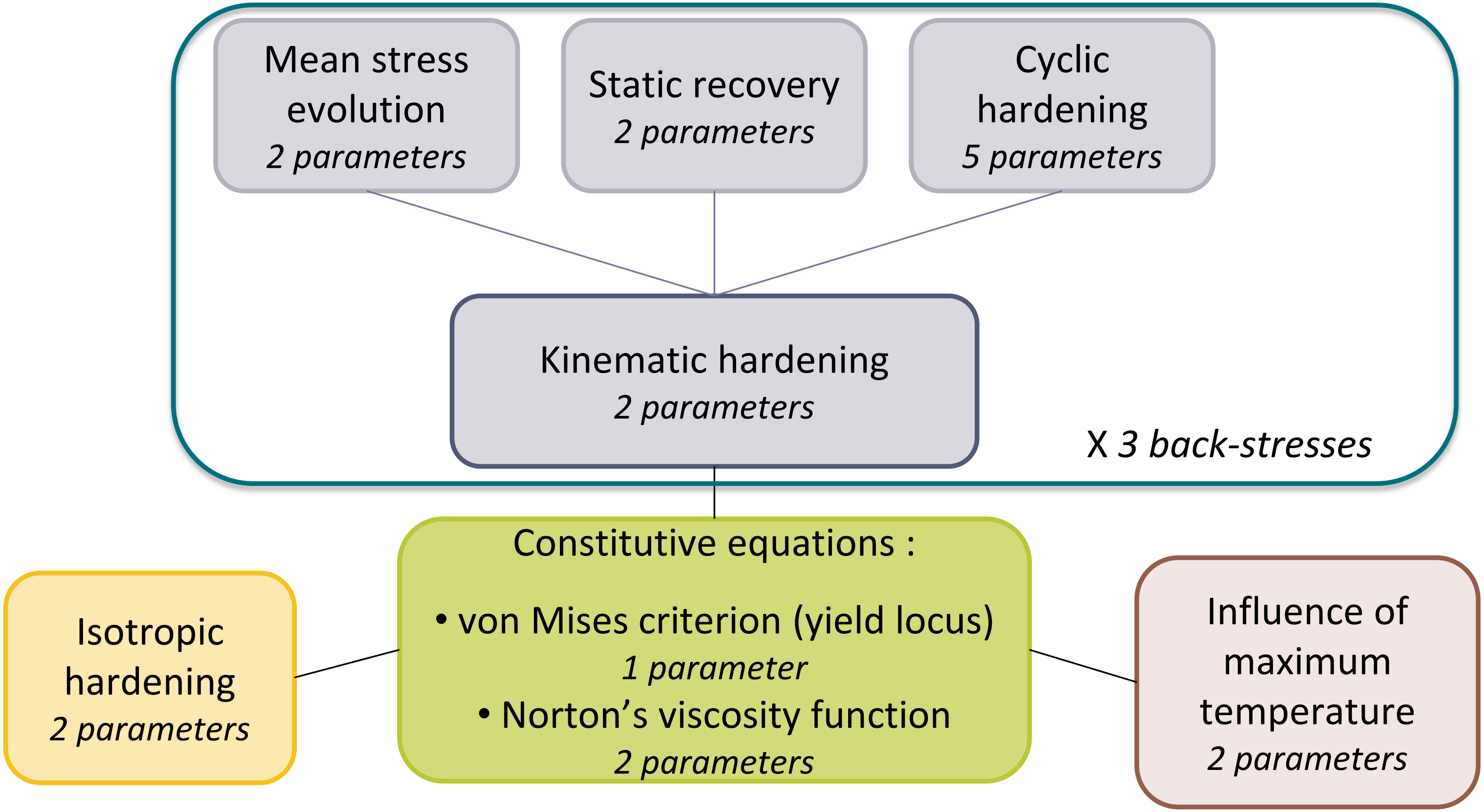
Context: The tubes

Temperature distribution in a tube
(Lagamine FE code)



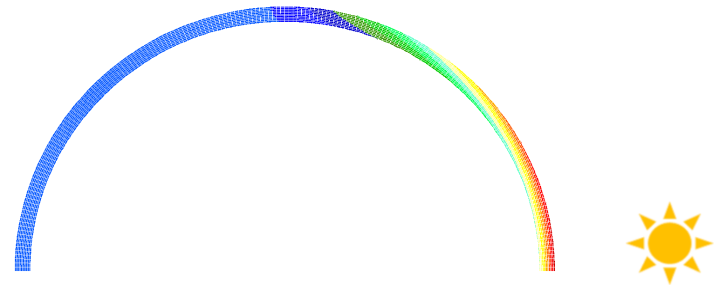
- **Fatigue + creep + corrosion**
- **Extreme Thermo-mechanical loading** (Haynes 230)
- **Advanced constitutive model + Damage**

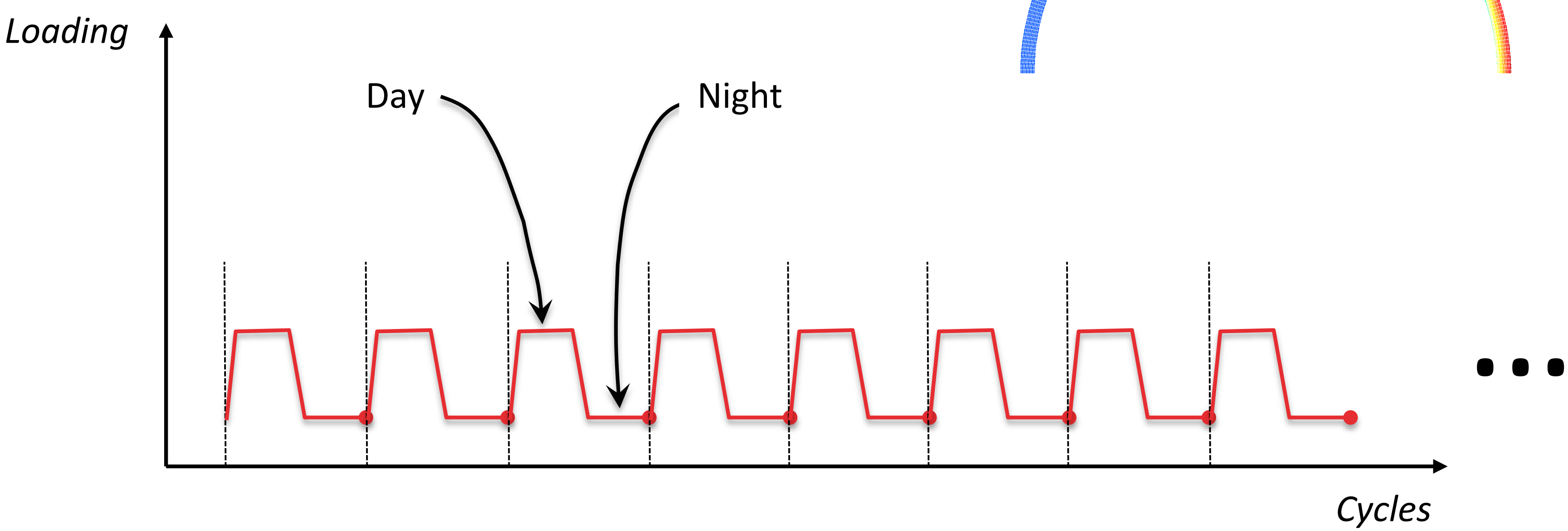
Advanced Chaboche model



+ Lemaitre Damage (creep + fatigue + corrosion)

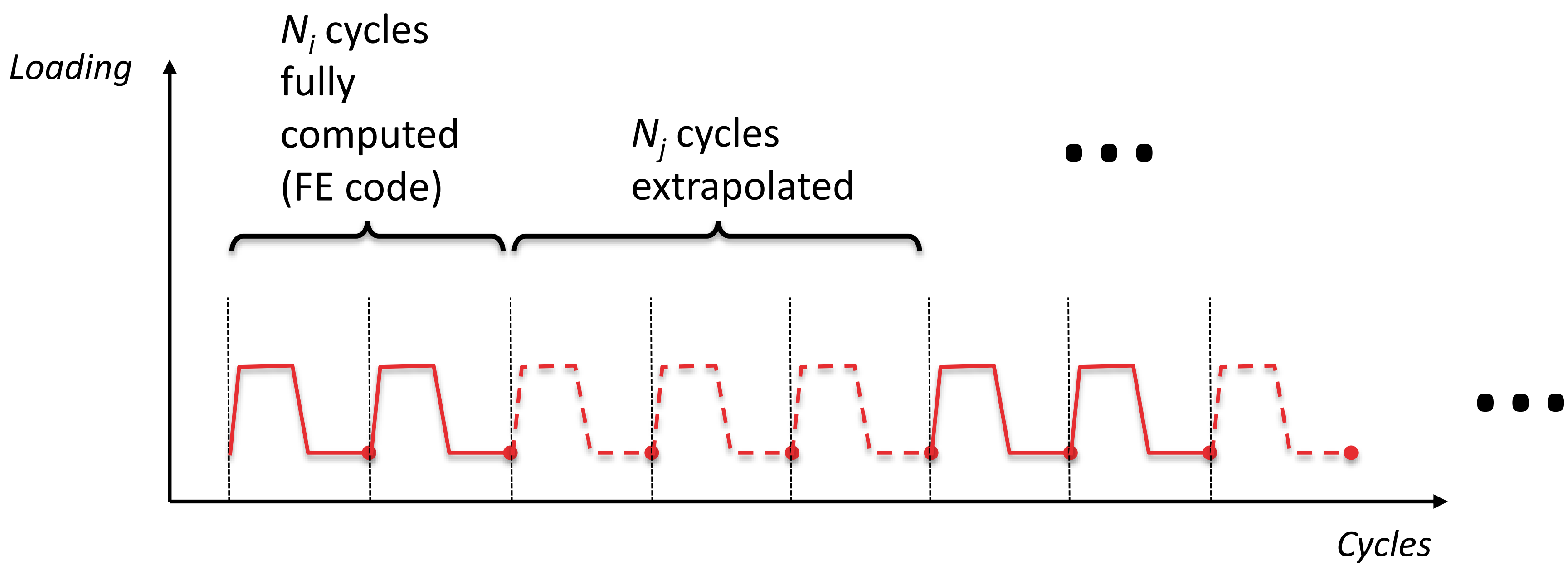
Cycle jump approach





Target:
- ▶ 10 000 cycles (~25 years)
- ▶ 18m long tube (~200 000 FE, 10^6 DOFs)

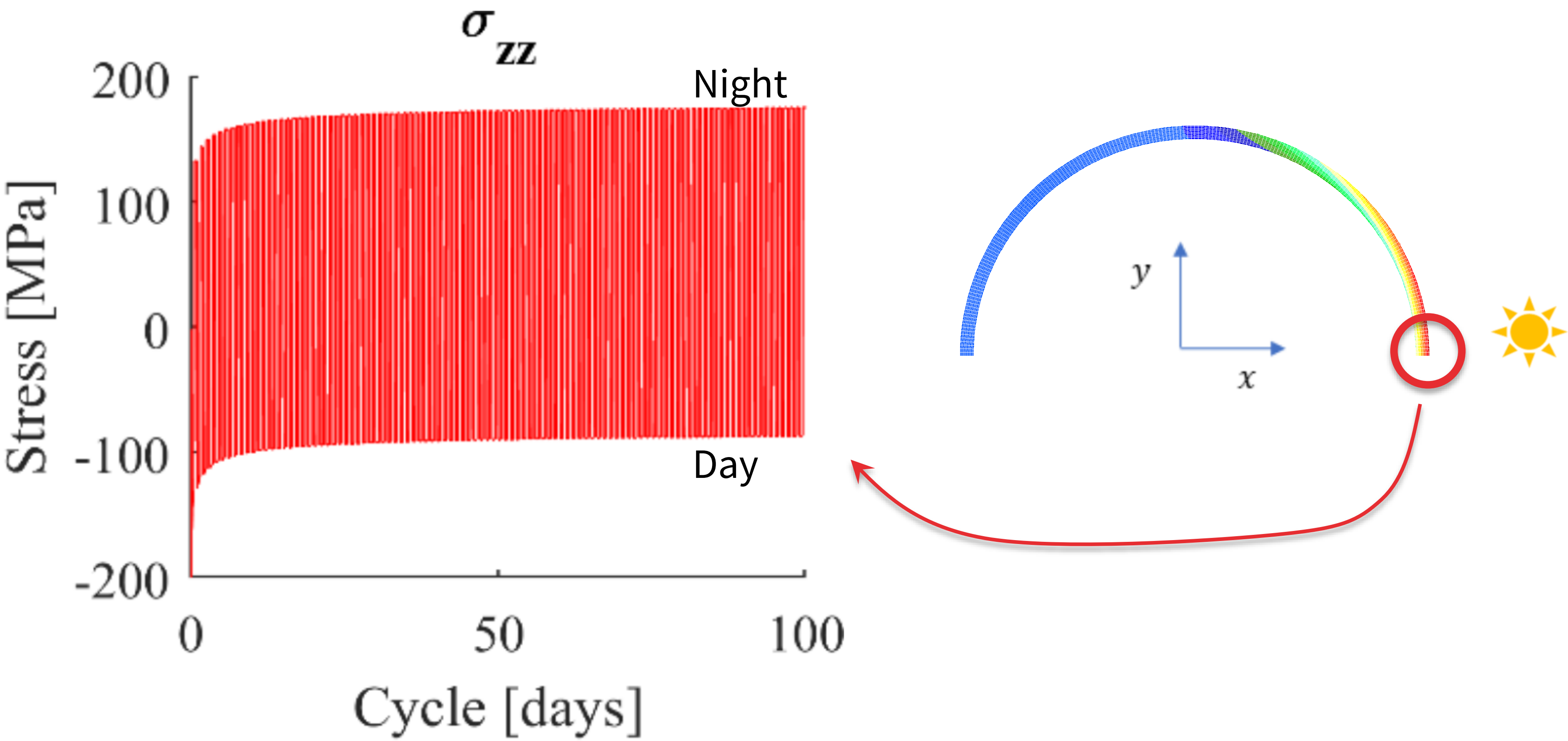
Cycle jump approach



Target:
- ▶ 10 000 cycles (~25 years)
- ▶ 18m long tube (~200 000 FE, 10^6 DOFs)

This study:
- ▶ 5 000 cycles
- ▶ 1 slice of the tube (300 FE, ~3000 DOFs)

Cycle jump: near-steady-state



➔ Full FE computation for the first 100 cycles

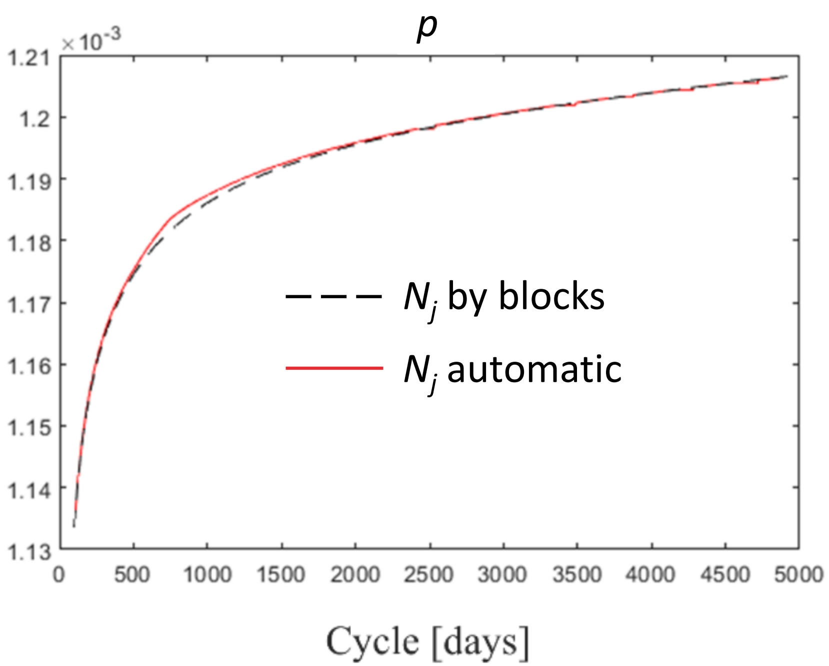
Cycle jump: effects of N_j

3 solutions implemented:

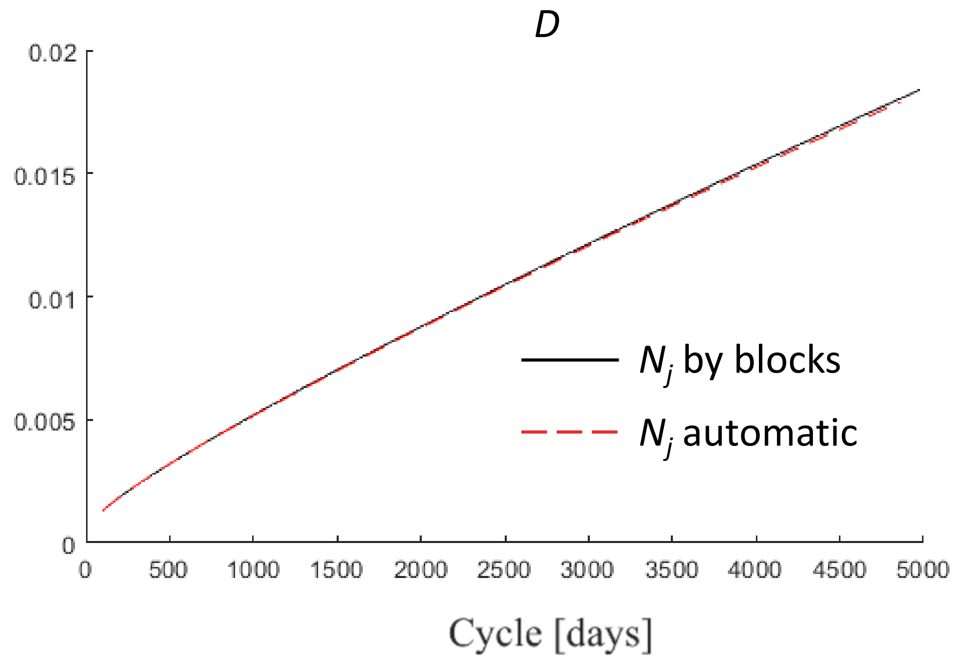
- Constant: user-defined value
- Constant by blocks: idem with predefined evolution (16…26…36)
- Automatic: adjusted by the code to limit ΔD over the jumped cycles for all elements ($\Delta D^{max} = 5.10^{-4}$)

Cycle jump: effects of N_j

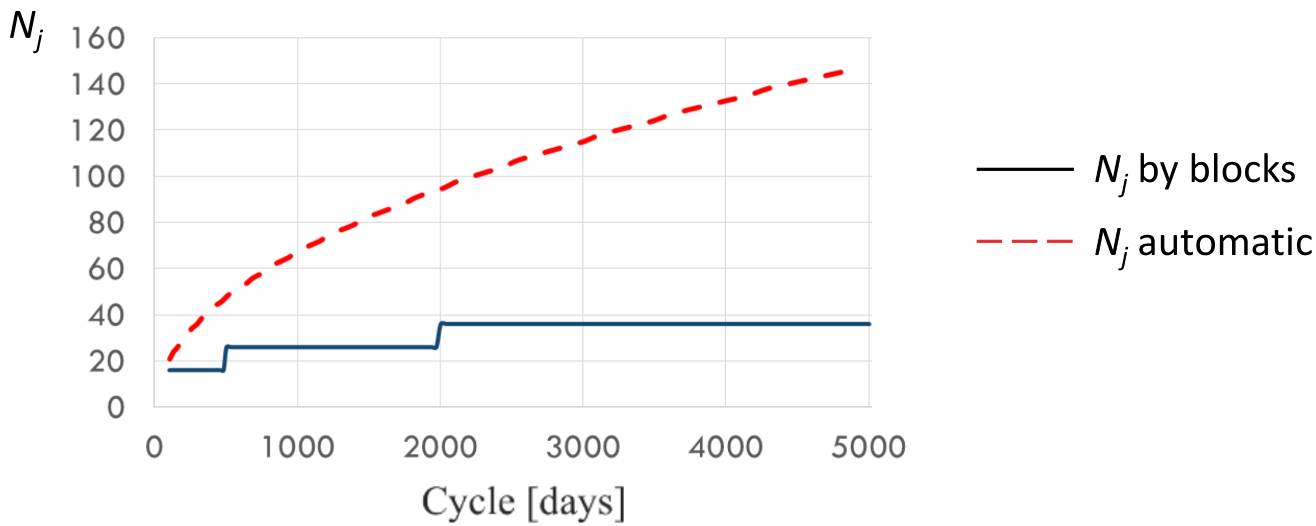
Total plastic strain



Total Damage



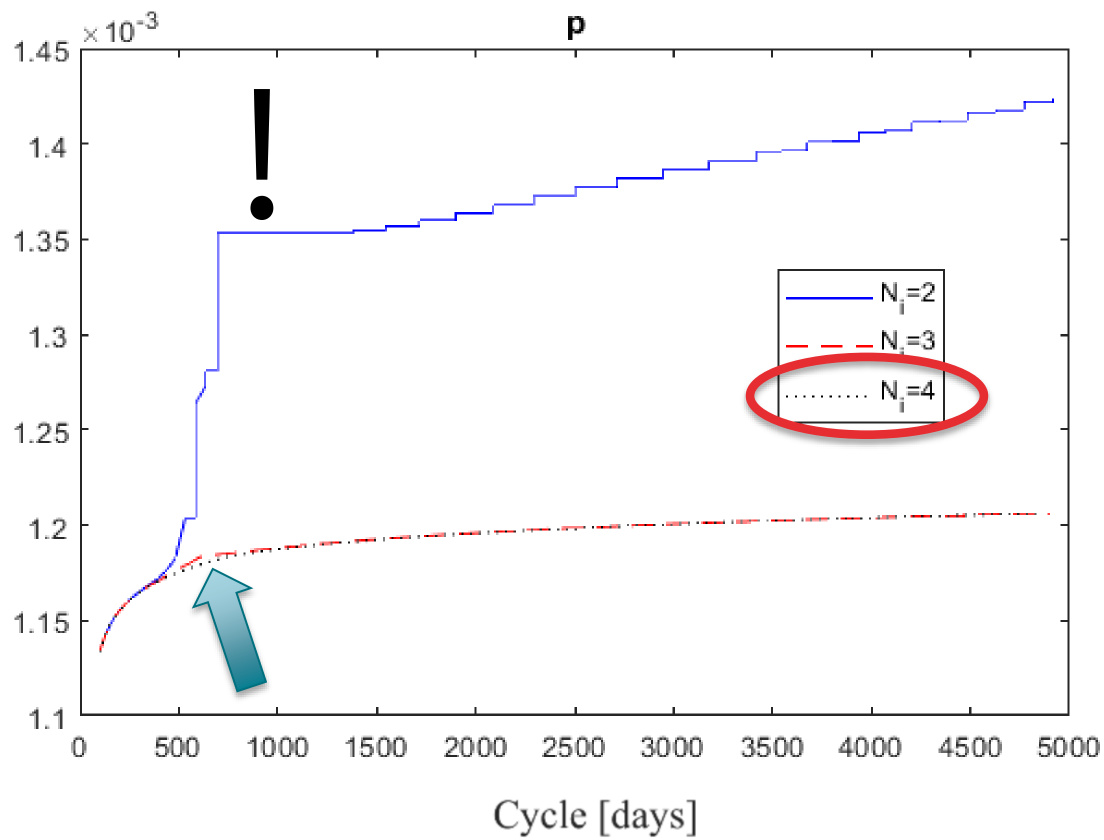
Cycle jump: effects of N_j



	FE cycles	Jumped cycles	Total	Number of jumps	Mean N_j
N_j by blocks	580	4420	5000	145	30
N_j automatic	220	4780	5000	55	87

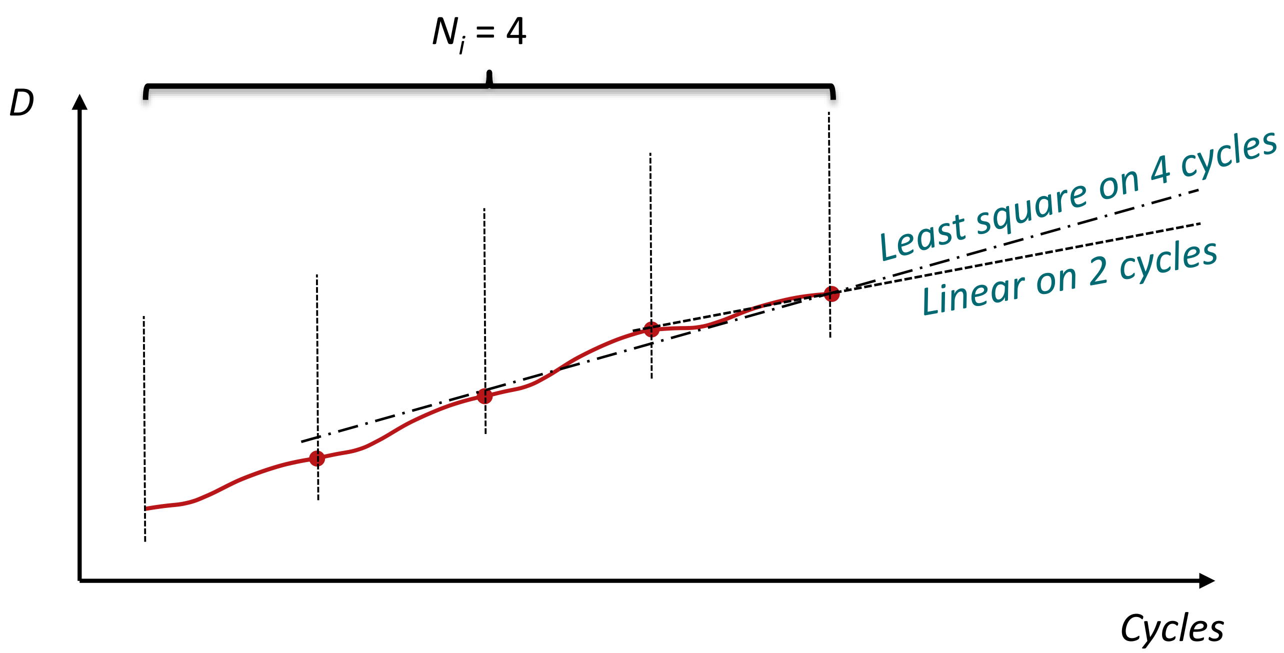
Cycle jump: effects of N_i

Total plastic strain



Cycle jump: extrapolation strategy

- Extrapolation scheme



➡ No significant effect

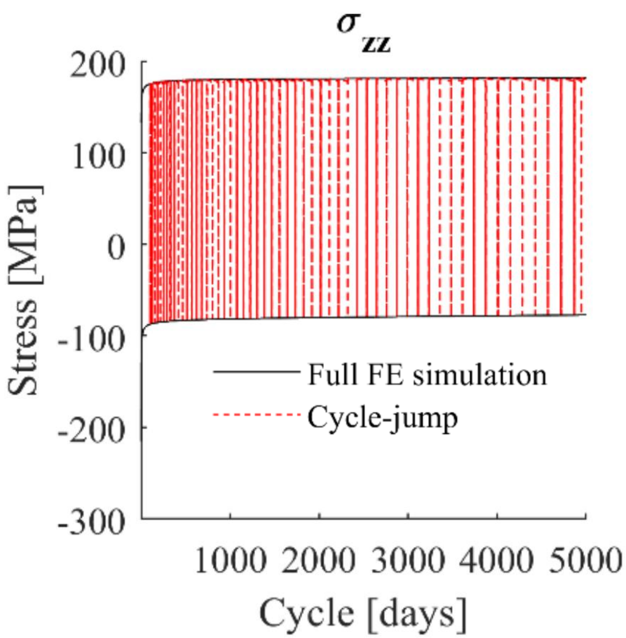
- Variables to extrapolate

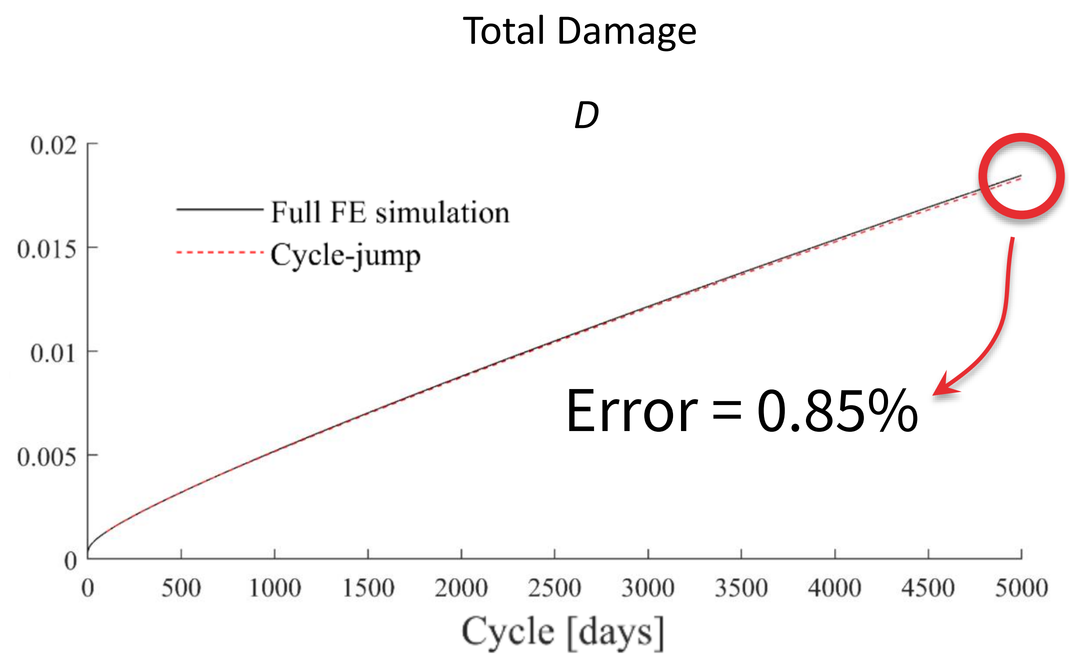
All FE variables, only *D*… ➡ No significant effect

Cycle jump: optimum parameters

- First 100 cycles → full FE computation
- $N_i = 4$
- N_j automatic ($\Delta D^{max} = 5.10^{-4}$)
- Extrapolation scheme: linear on 2 cycles
- All FE variables extrapolated

Cycle jump: optimum parameters





	CPU time (hours)
Full FE computation	104
Optimum Cycle jump	11

- 5 000 cycles
- 1 slice of the tube (300 FE, ~3000 DOFs)

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Modèle de base

$$\underline{\varepsilon} = \underline{\varepsilon}^{él} + \underline{\varepsilon}^{vp} + \underline{\varepsilon}^{th}$$

$$\underline{\sigma} = \underline{\underline{E}} : \underline{\varepsilon}^{él}$$

$$\underline{\dot{\sigma}} = \underline{\underline{E}} : \underline{\dot{\varepsilon}}^{él} + \underline{\underline{\dot{E}}} : \underline{\varepsilon}^{él}$$

Surface de plasticité

$$f = \|\underline{\sigma} - \underline{X}\| - \sigma_0 - R \leq 0$$

Contrainte visqueuse

$$\sigma_v = f > 0$$

Loi de viscosité

$$\dot{p} = \left\langle \frac{\sigma_v}{K} \right\rangle^n$$

$$Avec : \dot{p} = \sqrt{\frac{2}{3}\underline{\varepsilon}^{vp} : \underline{\varepsilon}^{vp}}$$

Ecrouissage cinématique

$$\underline{\hat{X}} = \sum_{i=1}^{nAF} \underline{\hat{X}}_i$$

$$\underline{\dot{\hat{X}}}_i = \frac{2}{3} C_i \underline{\dot{\varepsilon}}^{vp} - \gamma_i (\underline{\hat{X}}_i - \underline{Y}_i)\dot{p}$$

Restauration statique

$$\underline{\dot{\hat{X}}}_i = \ldots - b_i \|\underline{X}_i\|^{r_i - 1} \underline{\hat{X}}_i$$

Variations de température

$$\underline{\dot{\hat{X}}}_i = \ldots + \frac{1}{C_i}\frac{\partial C_i}{\partial T}\dot{T}\underline{\hat{X}}_i$$

Evolution de la contrainte moyenne

$$\underline{\dot{Y}}_i = -\alpha_{b,i}\left(\frac{3}{2}Y_{st,i}\frac{\underline{\hat{X}}_i}{\|\underline{X}_i\|} + \underline{Y}_i\right)\|\underline{X}_i\|^{r_i}$$

Ecrouissage cyclique

$$\dot{\gamma}_i = D_{\gamma i}(\gamma_i^0 - \gamma_i)\dot{p}$$

$$\gamma_i^0 = a_{\gamma i} + b_{\gamma i} e^{-c_{\gamma i} q}$$

Ecrouissage isotrope

$$\dot{R} = b(Q - R)\dot{p}$$

Influence de la température maximale

Influence sur l'écrouissage cyclique

$$\dot{D}_{\gamma i} = b_{D\gamma}(D_{\gamma i}^{T\max} - D_{\gamma i})\dot{p}$$

Evolution du module d'Young

$$E = f_E E + (1 - f_E)E_{T\max}$$

$$\dot{f}_E = b_E(f_E^S - f_E)\dot{p}$$