

**SIMPACK User Meeting 2011,
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**Two  User-Routines for
'Online' Stress and Damage Calculation**

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1. motivation and example model

part I: 2. online stress calculation
in an EMBS

3. online damage calculation
in an EMBS

- background
- implementation and usage
- verification
- some notes

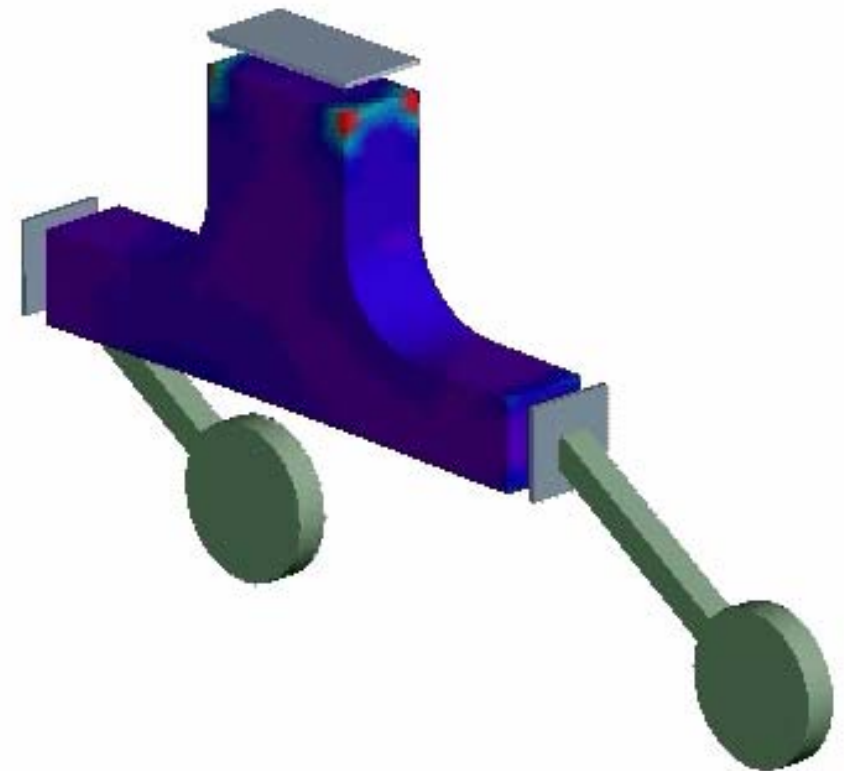
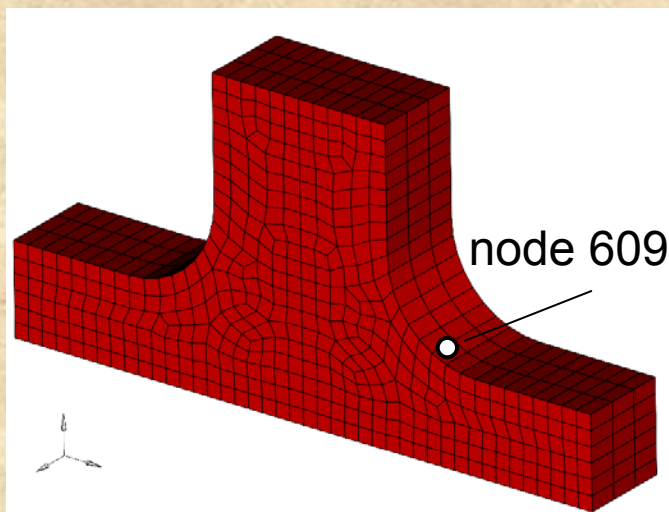
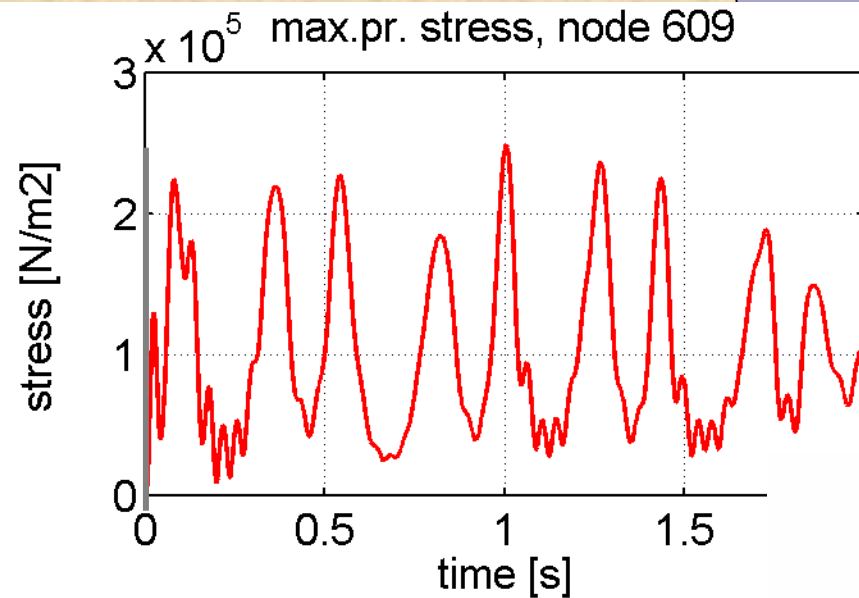
part II: 4. application examples

- structural optimization
- pseudo damage calculations

5. conclusions



Motivation and example

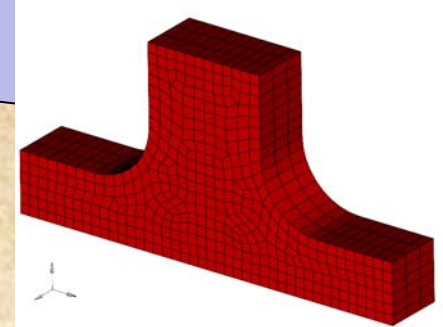


Theoretical background

displacement $\mathbf{u}(\mathbf{R}, t) = \Phi(\mathbf{R}) \cdot \mathbf{q}_{\text{fem}}(t)$

stress $\boldsymbol{\sigma}(\mathbf{R}, t) = \mathbf{H} \cdot \mathbf{D}_{\text{eu}} \cdot \mathbf{u}(\mathbf{R}, t)$

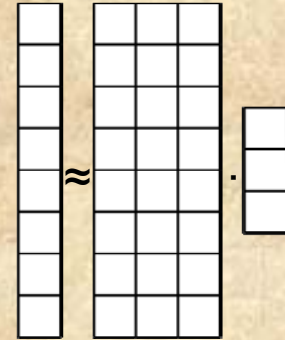
FEM



projection $\mathbf{q}_{\text{fem}}(t) \approx \mathbf{V} \cdot \mathbf{q}_{\text{red}}(t)$

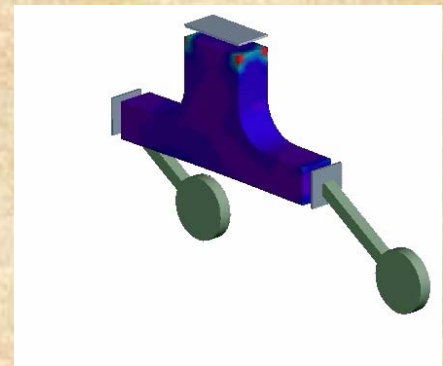
$\boldsymbol{\sigma}(\mathbf{R}, t) \approx \mathbf{H} \cdot \mathbf{D}_{\text{eu}} \cdot \underbrace{\Phi(\mathbf{R}) \cdot \mathbf{V}}_{\text{stress modes } \Phi_{\sigma, \text{red}}(\mathbf{R})} \cdot \mathbf{q}_{\text{red}}(t)$

MOR



equation of motion $\mathbf{M} \cdot \begin{bmatrix} \dot{\mathbf{y}}_{\text{II}} \\ \ddot{\mathbf{q}}_{\text{red}} \end{bmatrix} + \mathbf{k} = \mathbf{h}$

EMBS



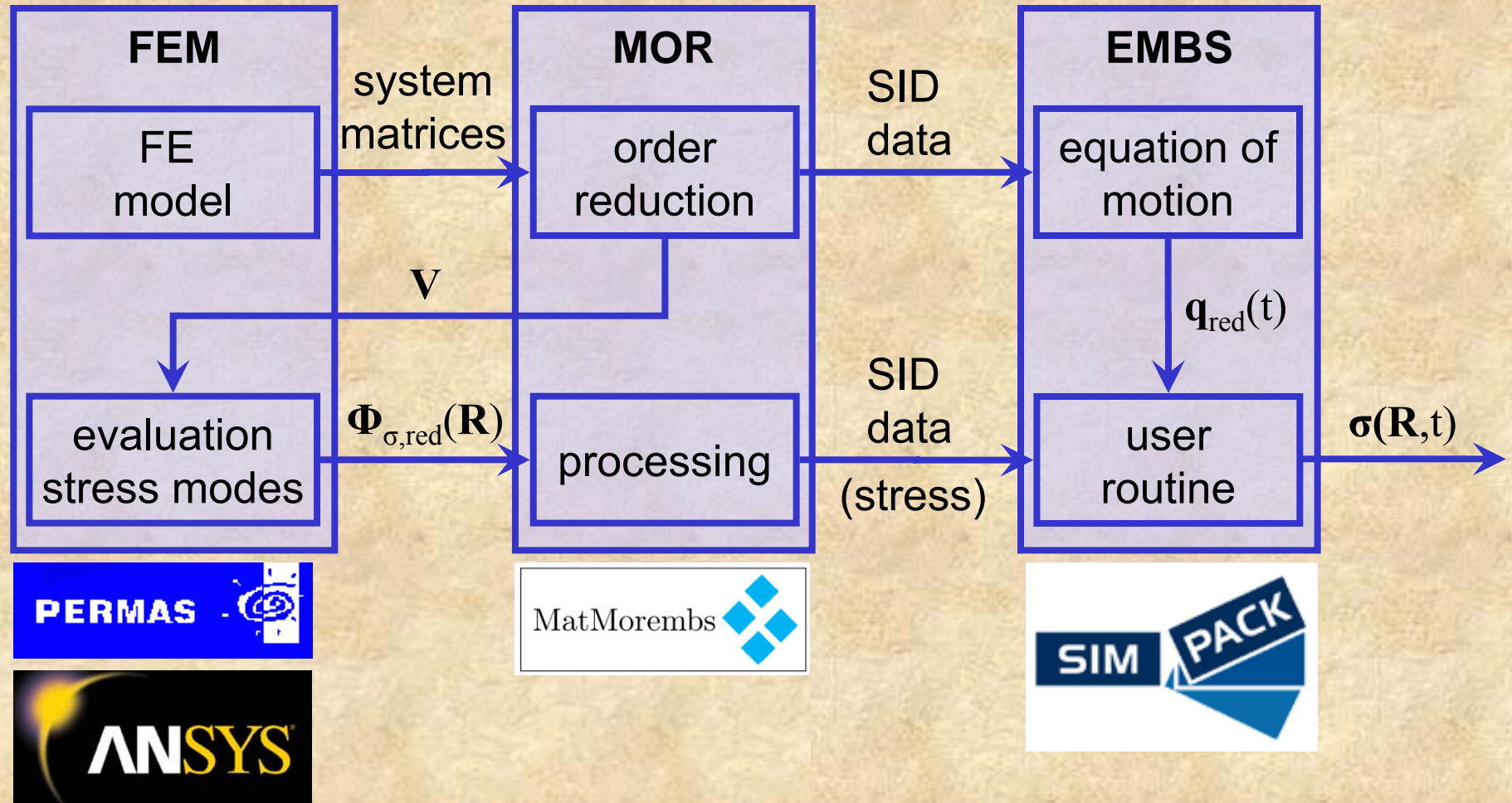
stress calculation

$\boldsymbol{\sigma}(\mathbf{R}, t)$ during EMBS-runtime



Implementation and usage

process chain



Implementation and usage

SID data for nodal stresses

```
new node = 792
sigma
  order = 1
  nrow = 6
  ncol = 1
  nq = 36
  nqn = 0
  structure = 3
  m1( 1, 1, 1) = -2.9608500000000E+06
  m1( 1, 2, 1) = -1.8886320000000E+06
  m1( 1, 3, 1) = 2.1136120000000E+06
```

class
'taylor'

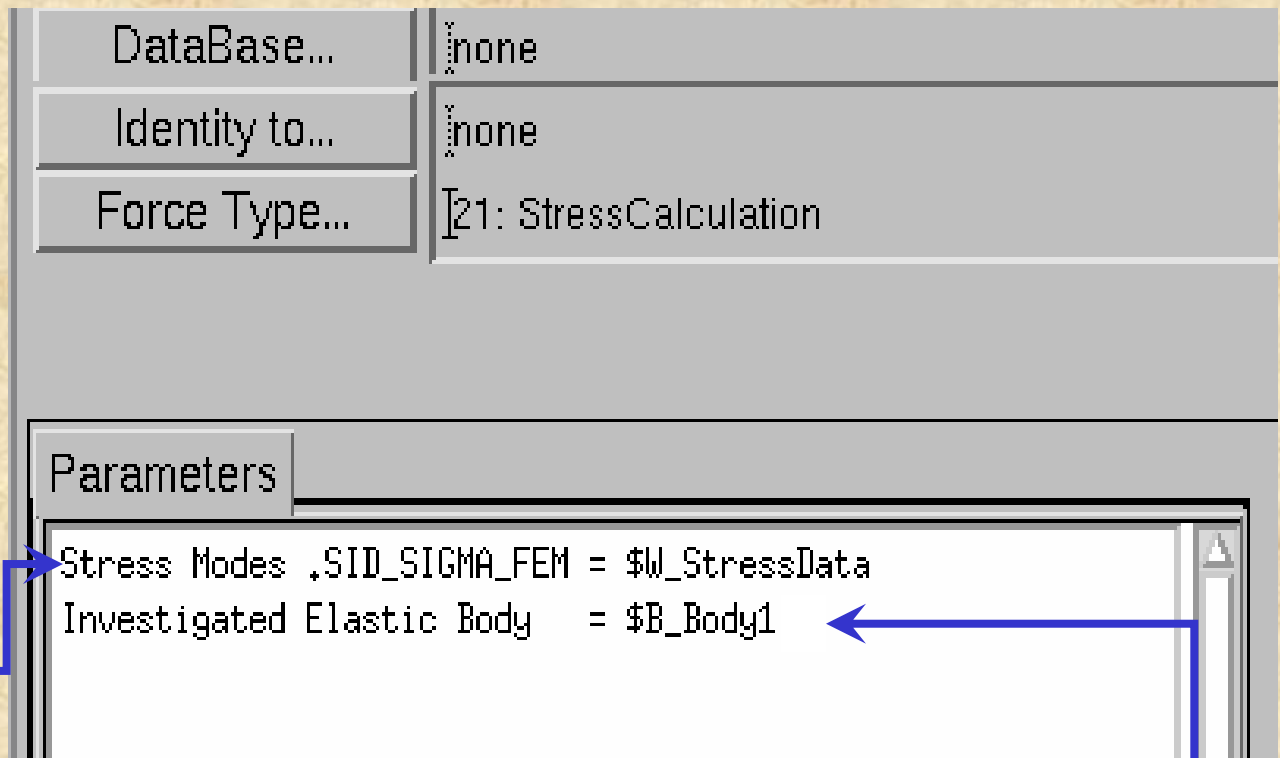
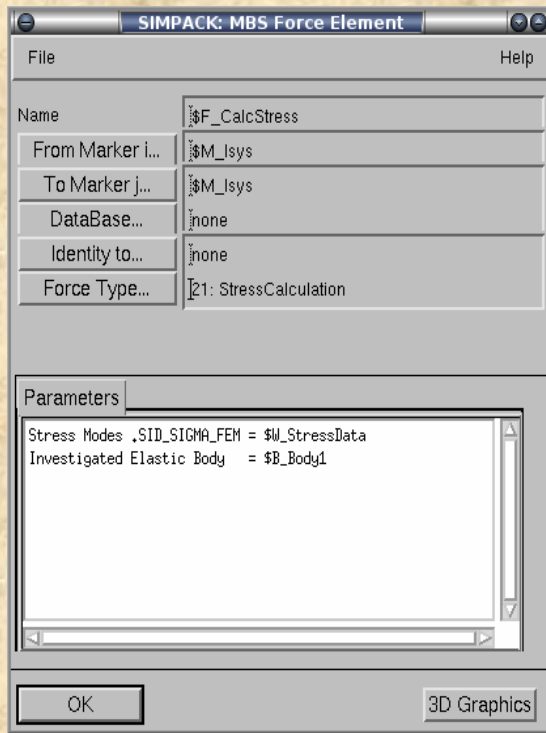
class 'node'
object 'sigma'

class 'node' contains an additional object 'sigma', which is of class 'taylor'



SIMPACK preprocessor-GUI

Implementation and usage



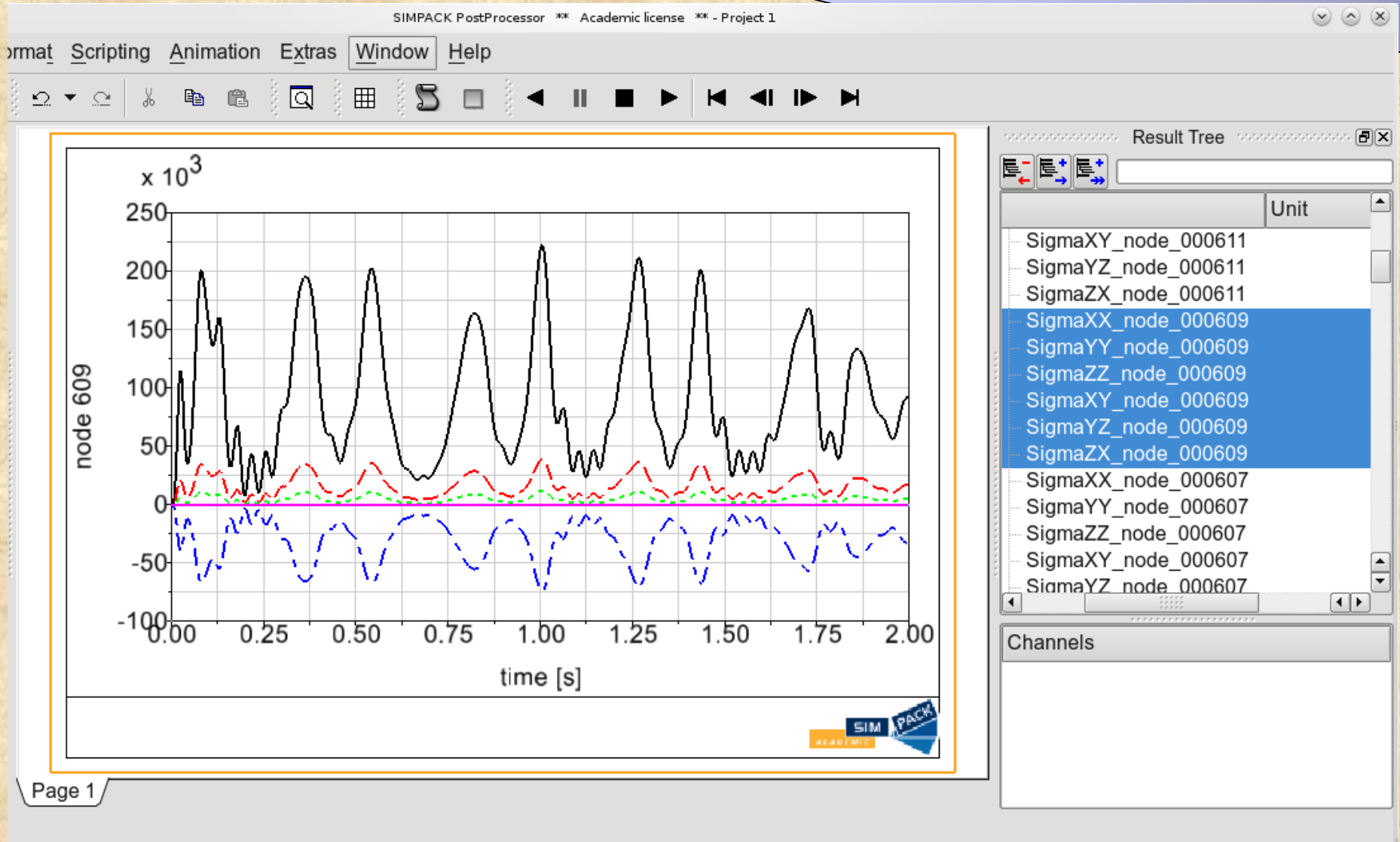
SID file with nodal stress modes $\Phi_{\sigma,red}(\mathbf{R})$

body holding elastic coordinates $\mathbf{q}_{red}(t)$

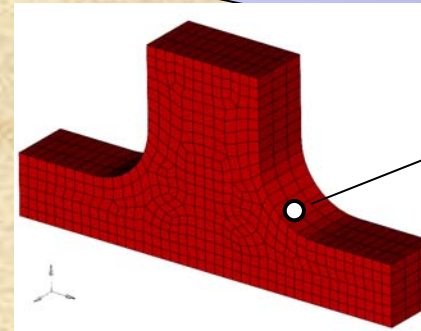
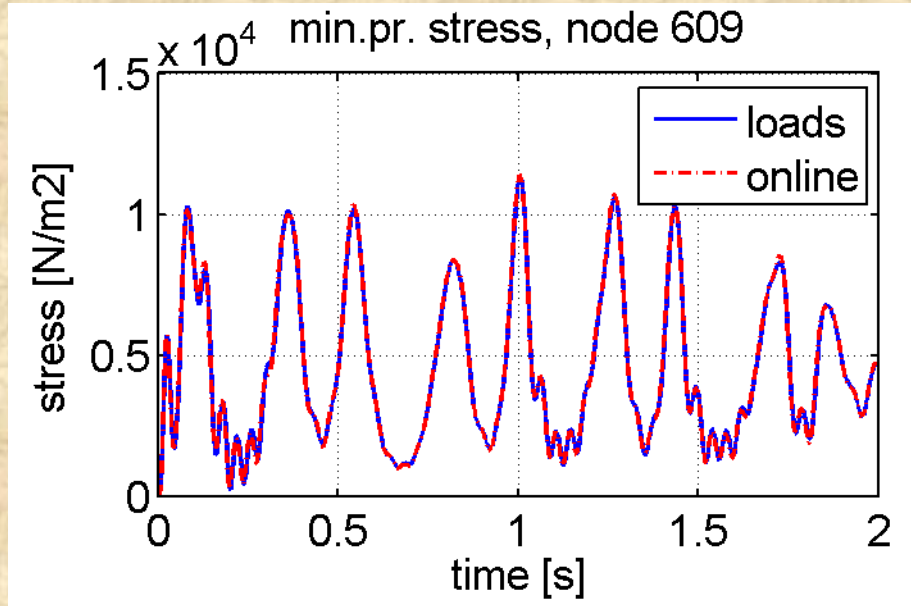


SIMPACK postprocessor-GUI

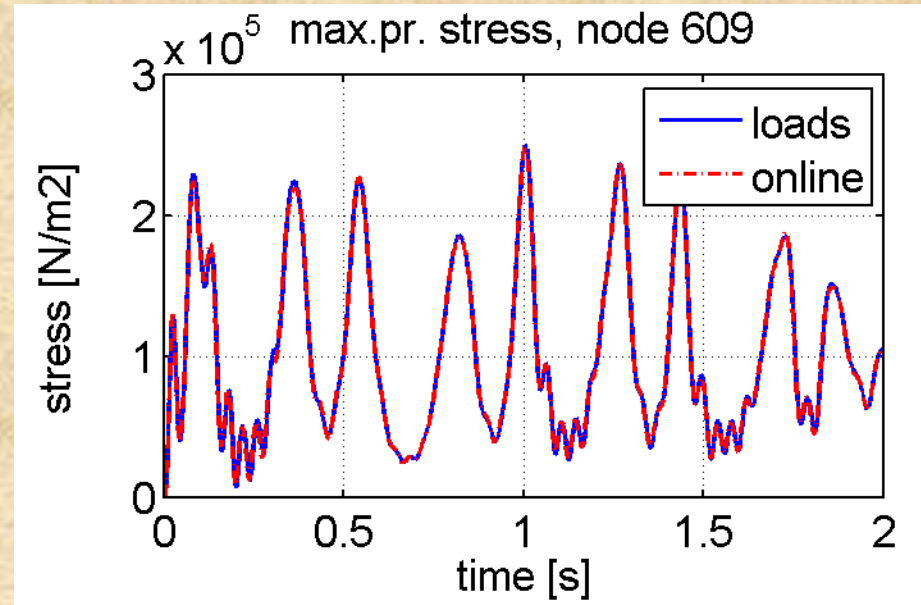
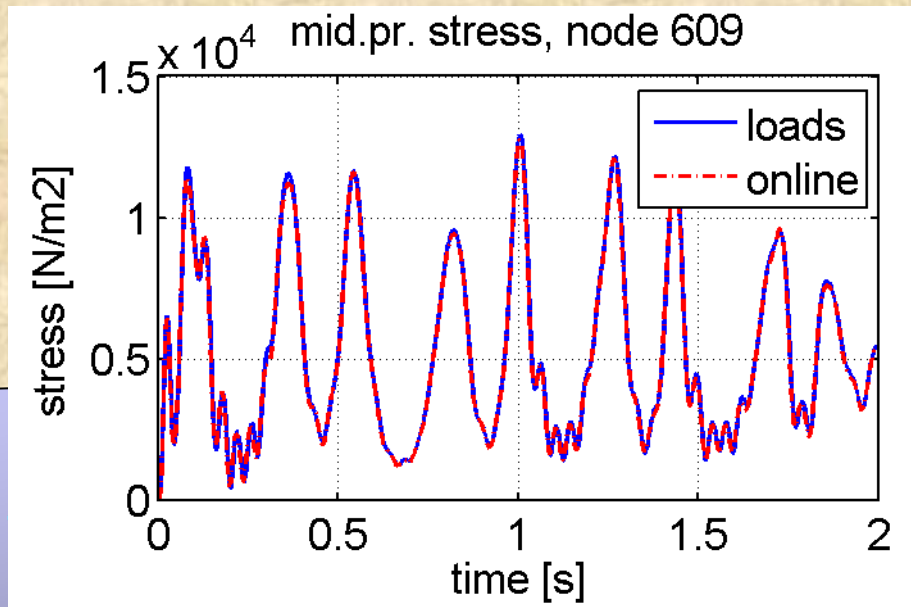
Implementation and usage



Verification



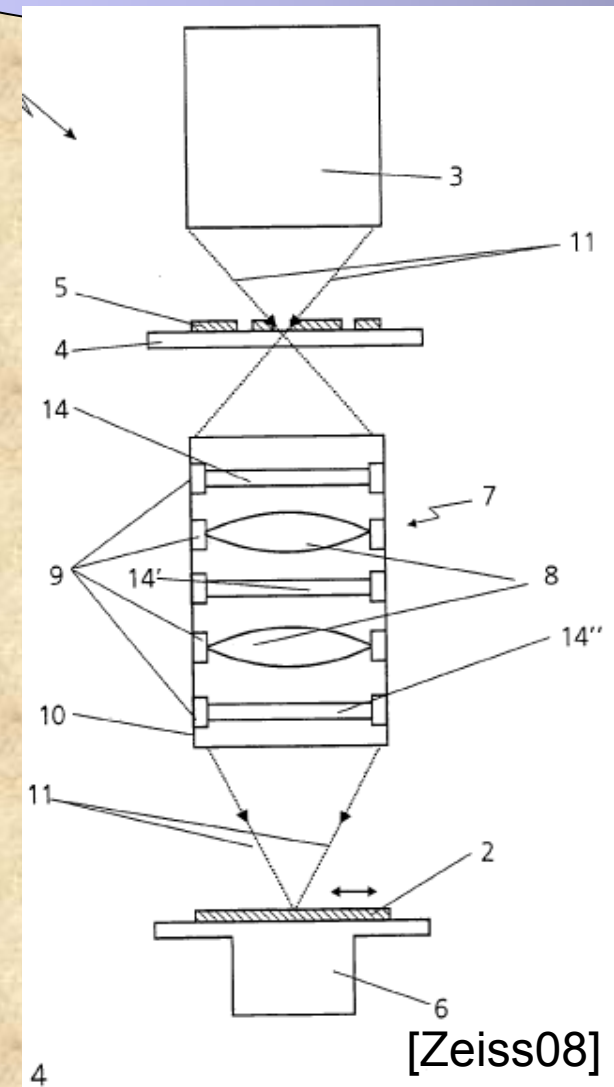
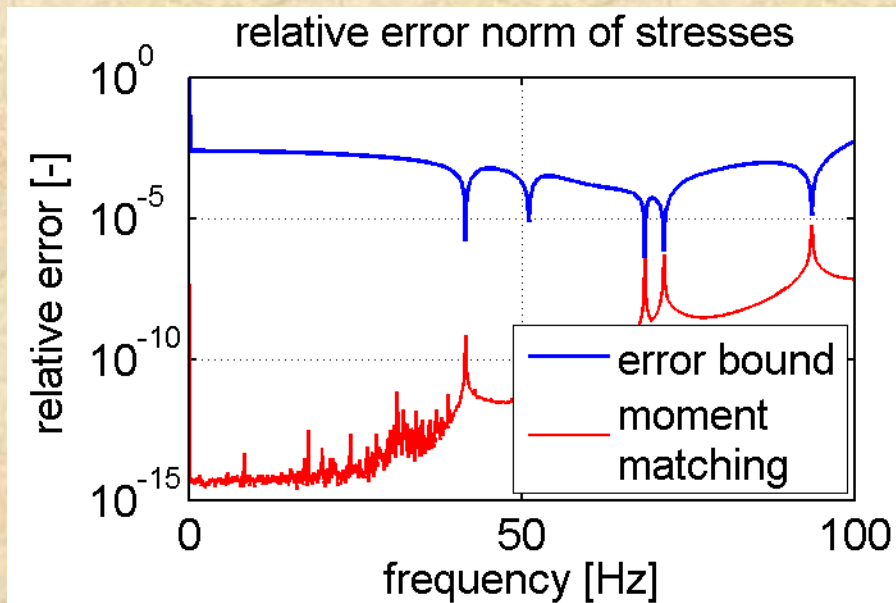
node 609



reference solution calculated
by SIMPACK/Loads (and NASTRAN)

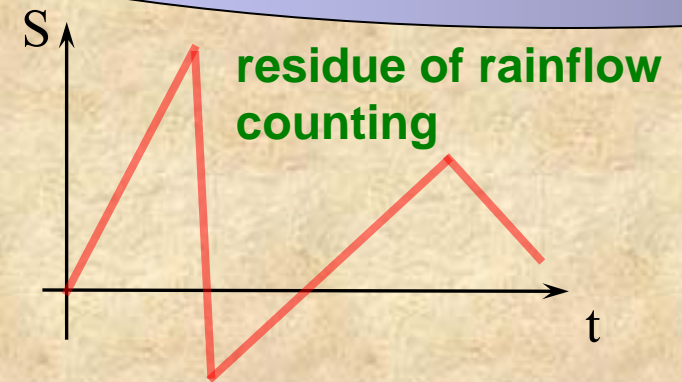
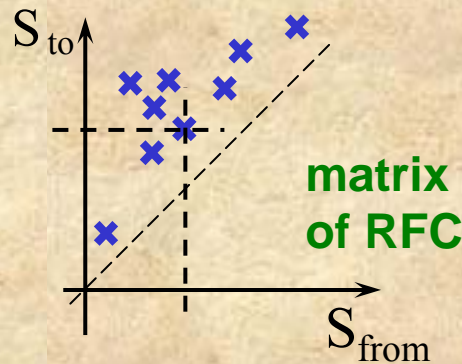
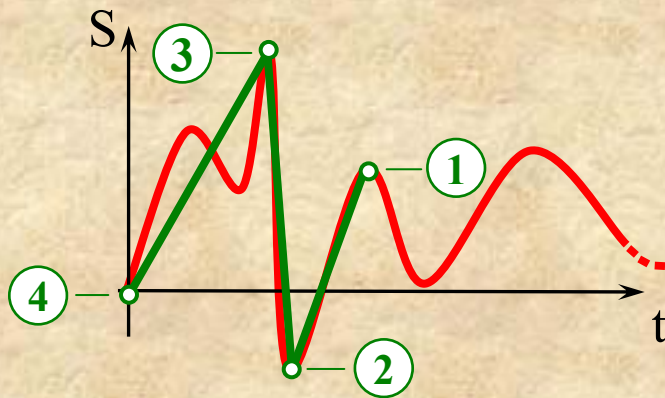
Some notes

1. usage of advanced model reduction techniques (e.g. Krylov-subspace techniques) ensure **small errors and/or error bounds** for the calculated stress
2. online stress calculation is necessary for some **control problems**, e.g. deformable lenses
3. online stress calculation is necessary for **online damage calculation**

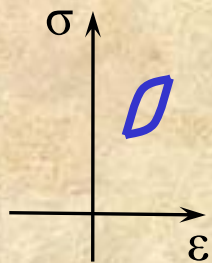


Theoretical background

rainflow counting



move through turning points in the load signal 'little by little' with a so-called 4-point-stack



fill / move 4-point-stack

are points ② and ③ inside the range spanned by ① and ④?

yes

no

identification of alternation from ② to ③ as closed hysteresis loop

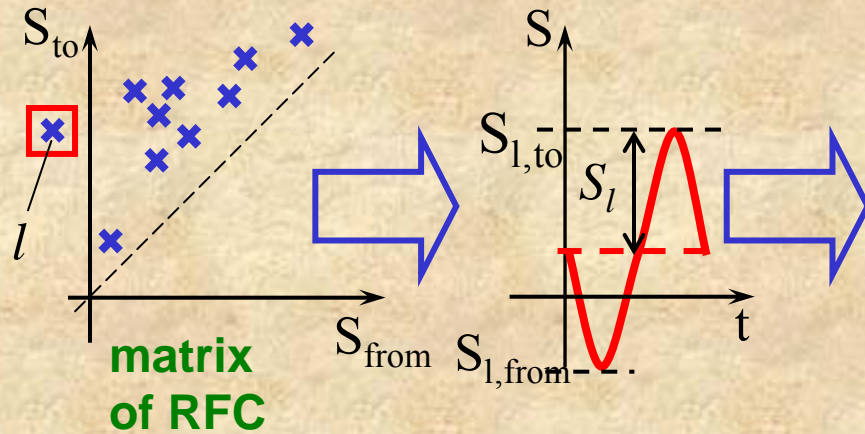
fill matrix of rainflow cycles (RFC)

delete points ② and ③ from load signal

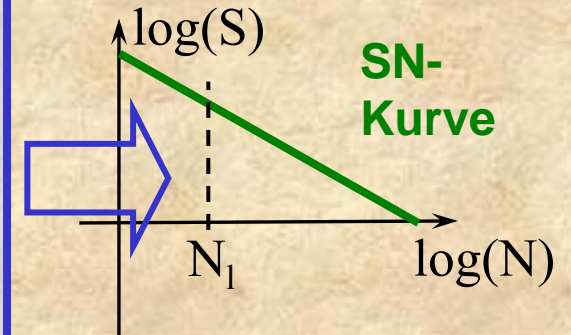


Theoretical background

damage accumulation



further calculations:
- mean stress influence
- yielding?
- ...

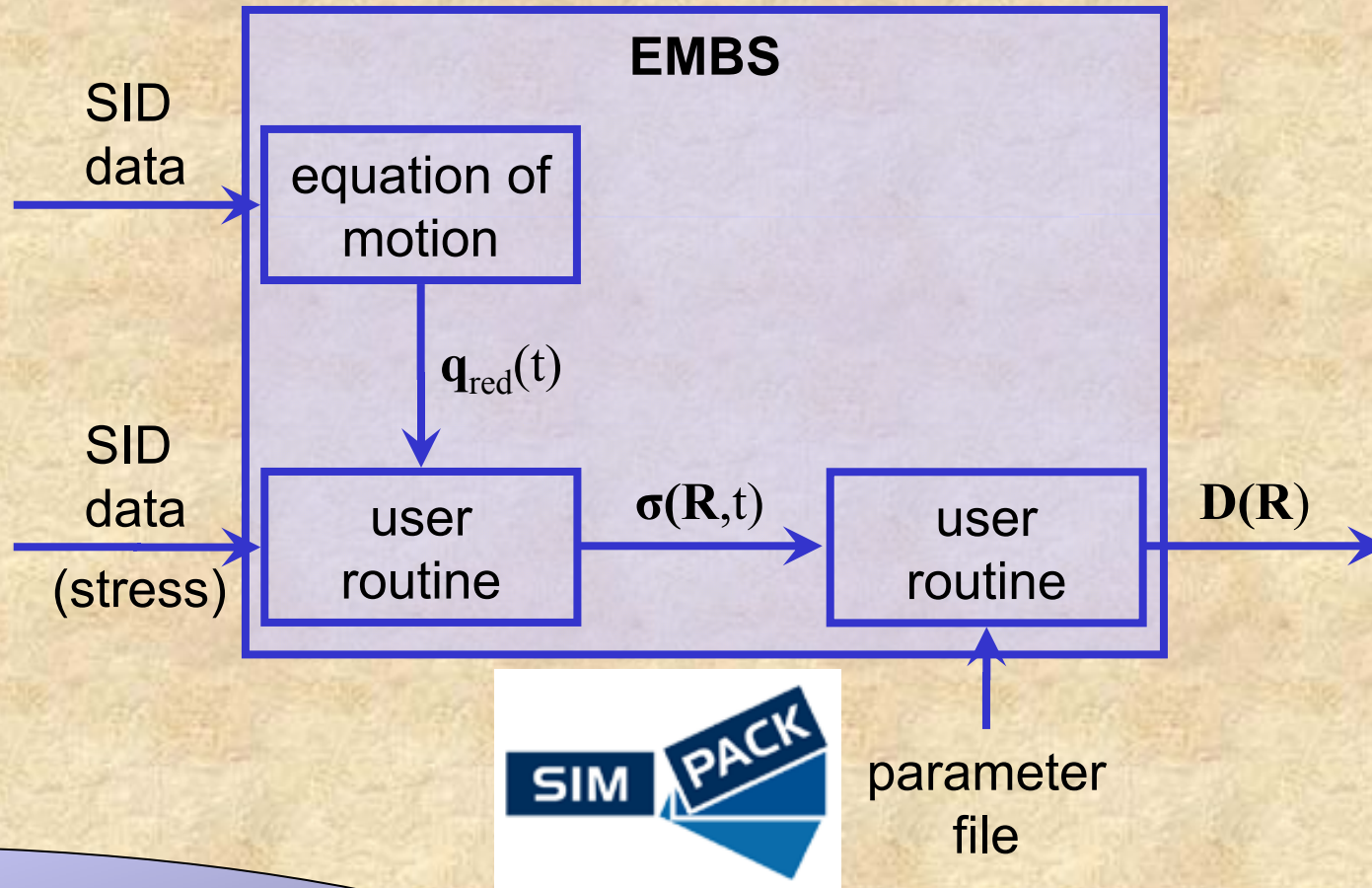


$$\Delta D_1 = \frac{1}{N_1} = \frac{1}{N_A} \left(\frac{S_l}{S_A} \right)^b$$

damage accumulation
 $D = \sum_i \Delta D_i$
damage value

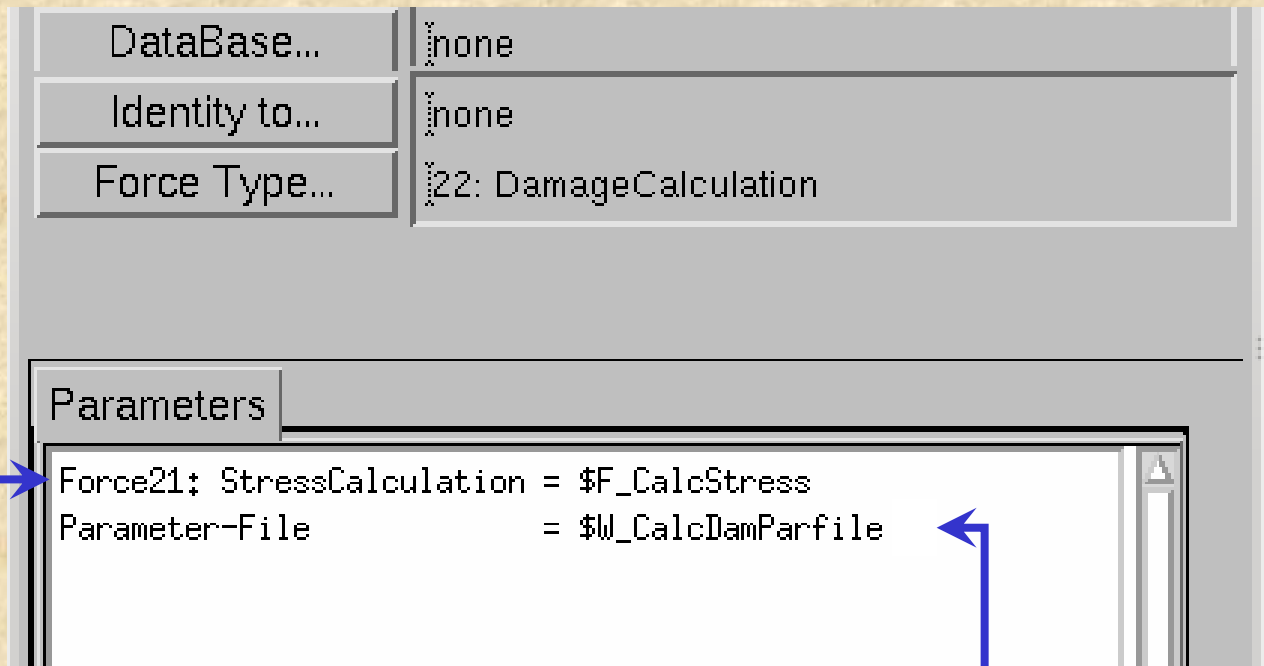
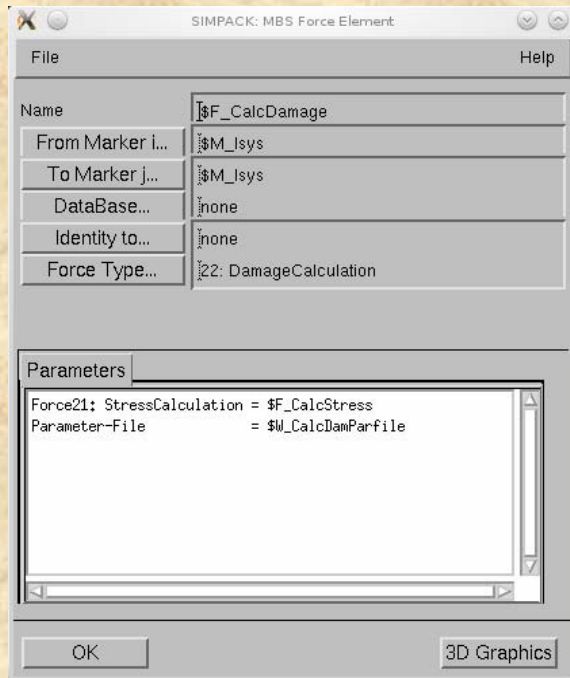
Implementation and usage

process chain

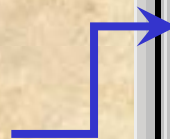


SIMPACK preprocessor-GUI

Implementation and usage



load channel
 $\sigma(\mathbf{R},t)$

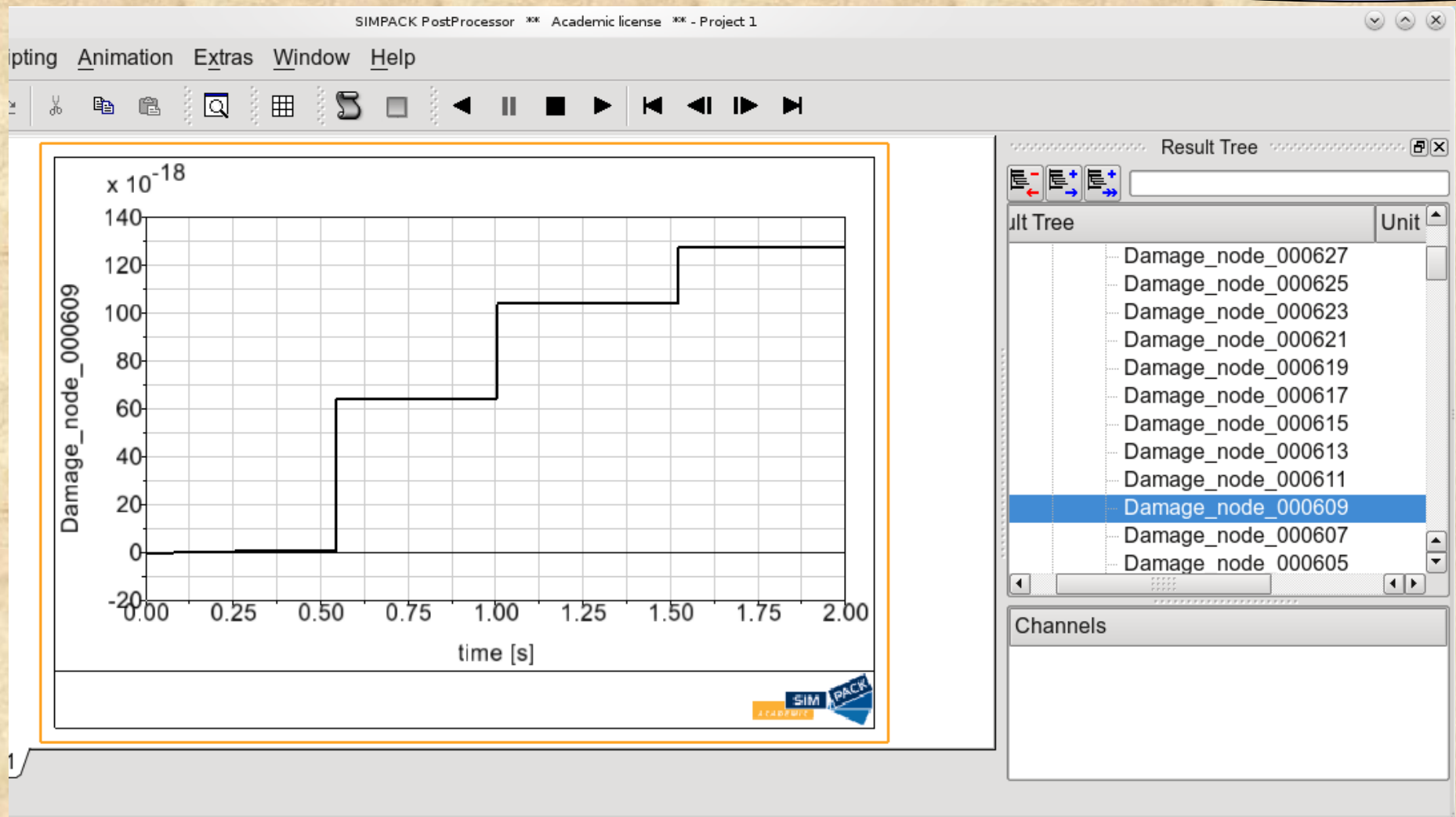


parameter
file

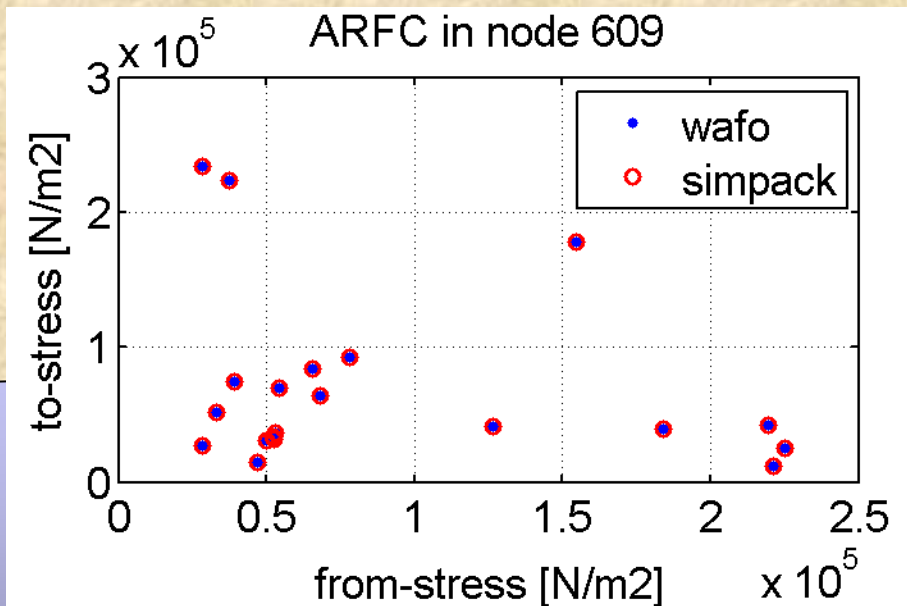
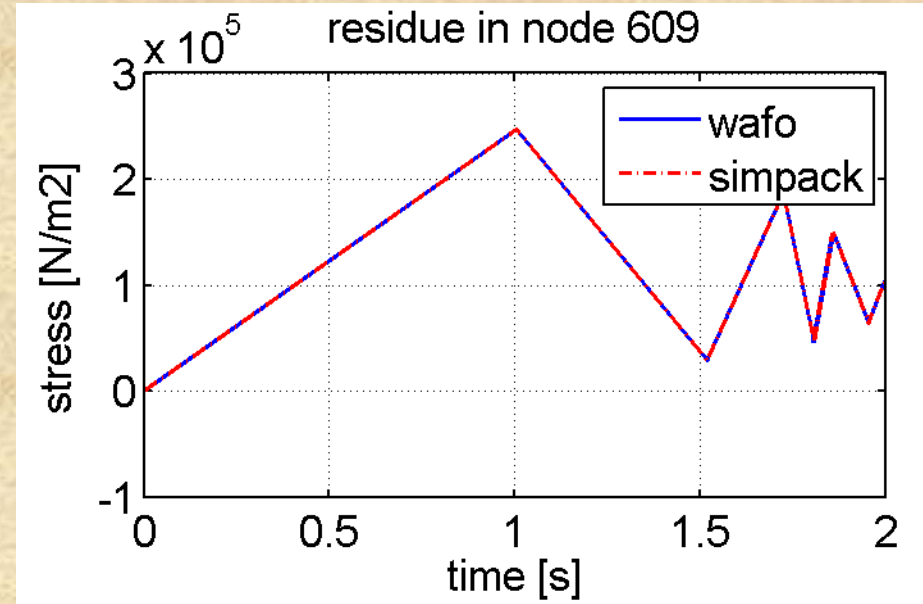
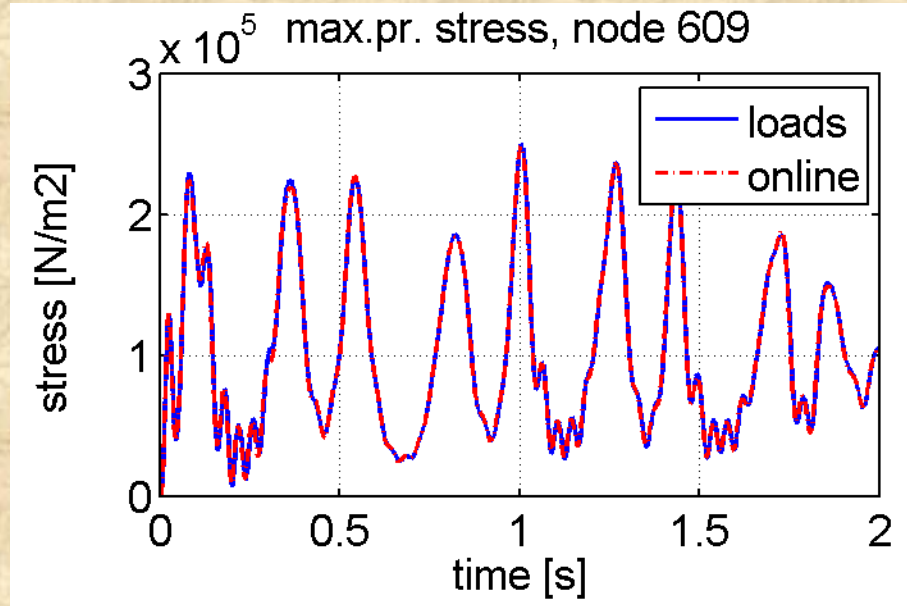


Implementation and usage

SIMPACK postprocessor-GUI



Verification

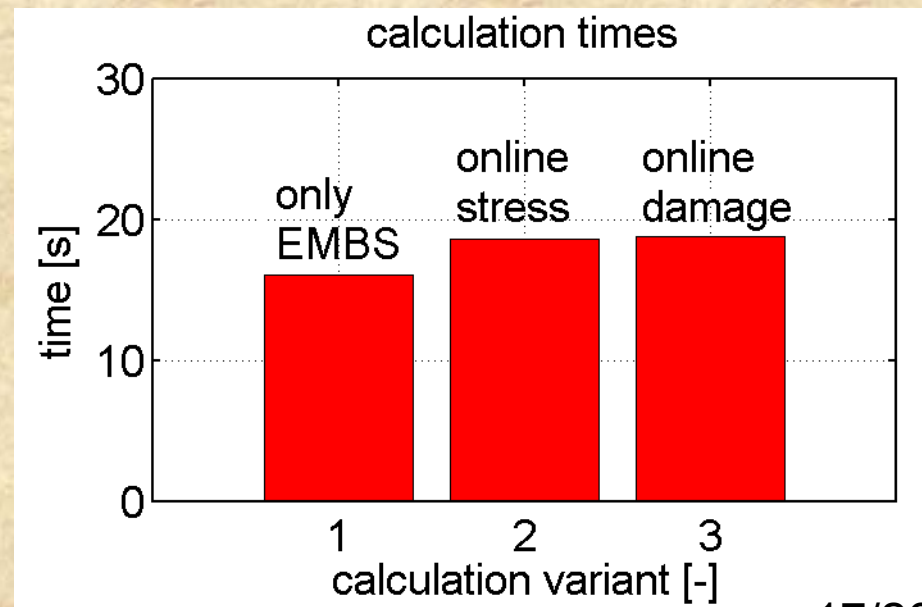
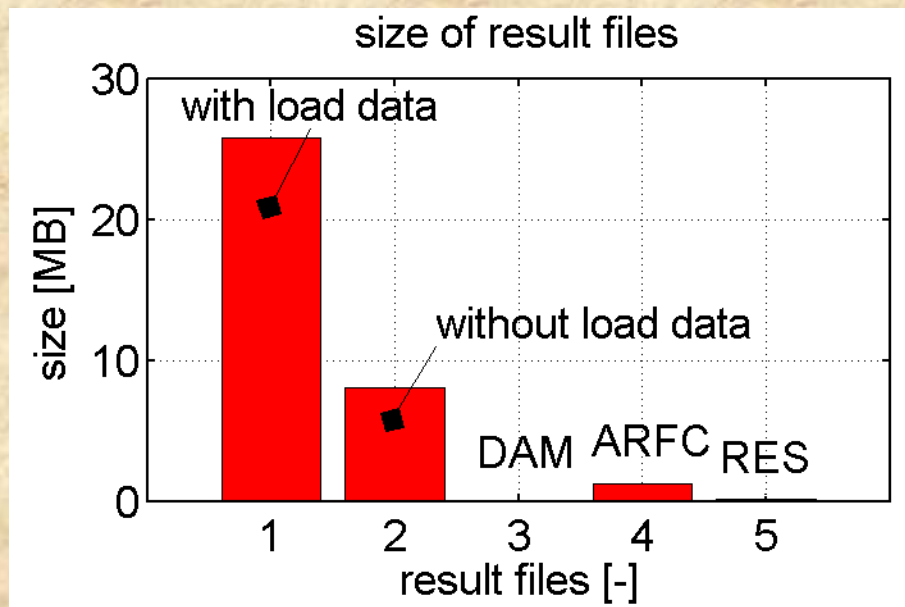


damage wafo	-15.80621
damage simpack	-15.80620

reference solution calculated
by MATLAB/Wafo

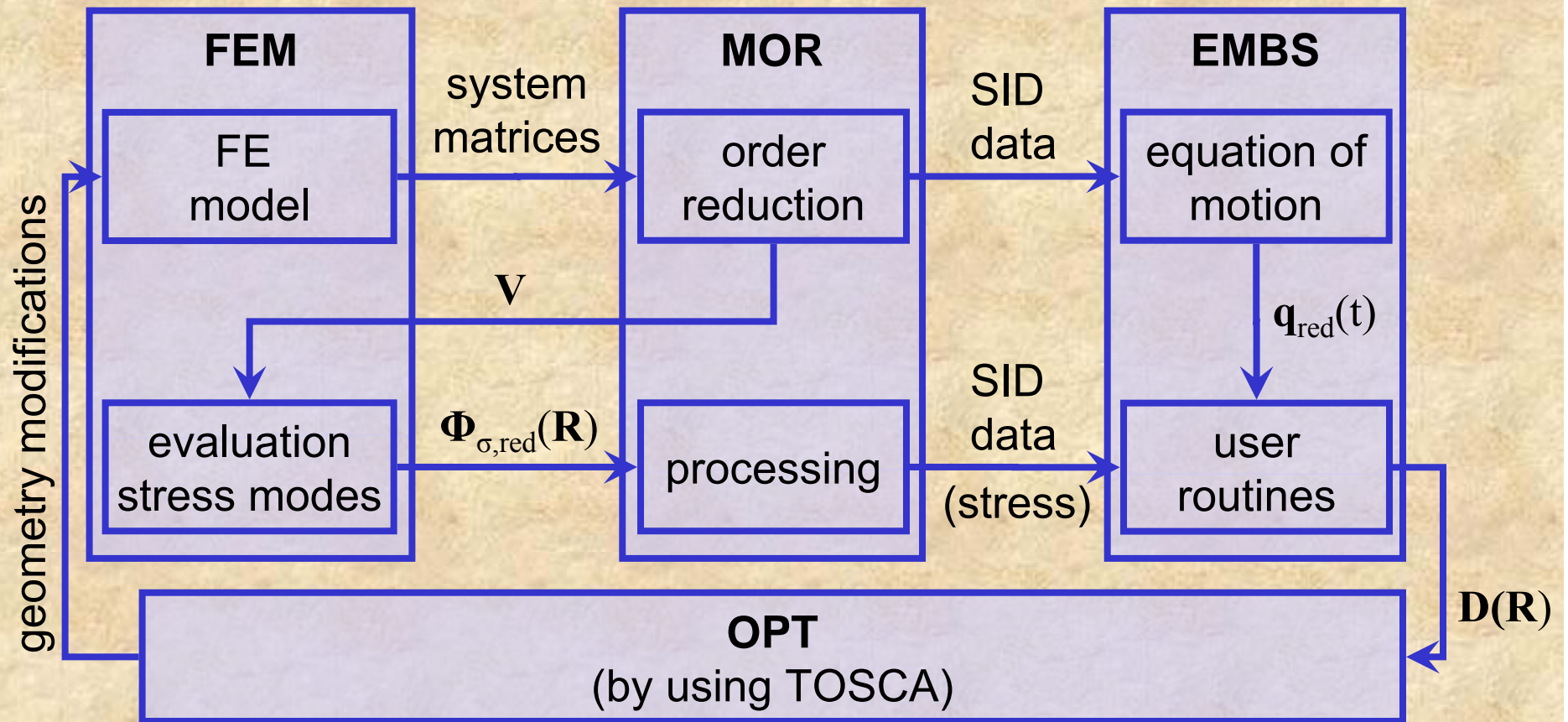
Some notes

1. by using an **EMBS-adapted 4-point-algorithm**, the storage of load data (e.g. forces, elastic coordinates, stresses, ...) is not necessary
2. online damage calculation provides a **scalar performance criterion** for load channels in terms of durability
3. regarding **calculation times**, the online damage calculation is (usually) not very costly

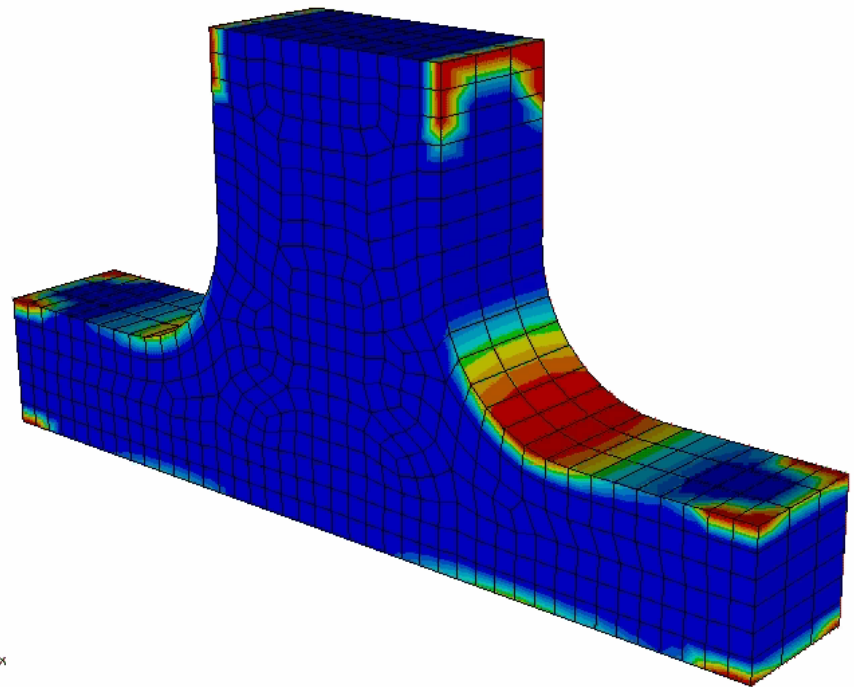
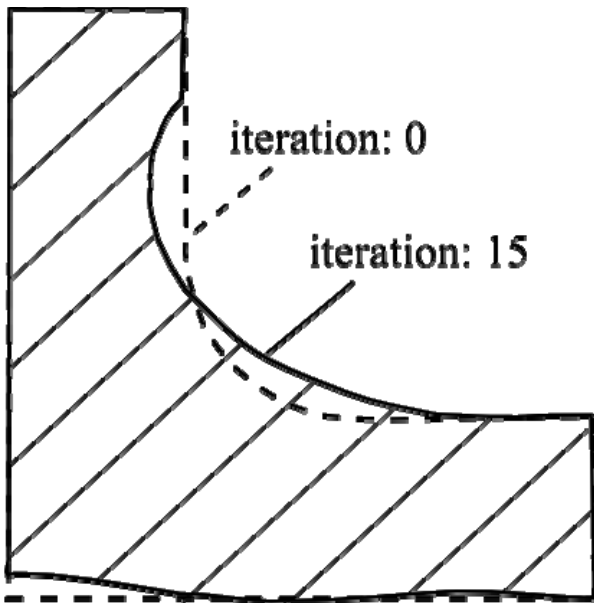
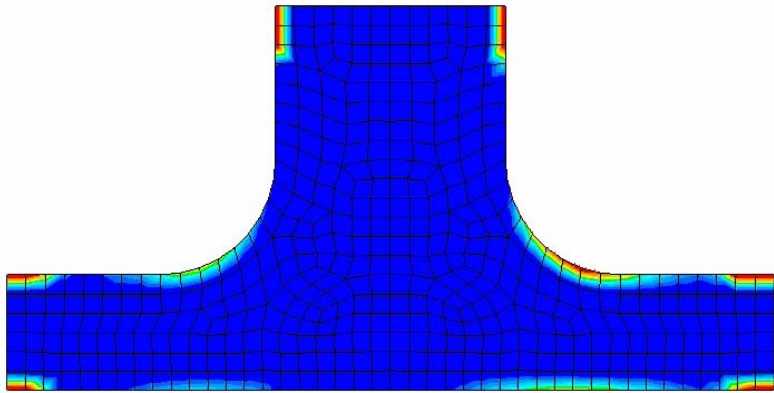


Structural optimization

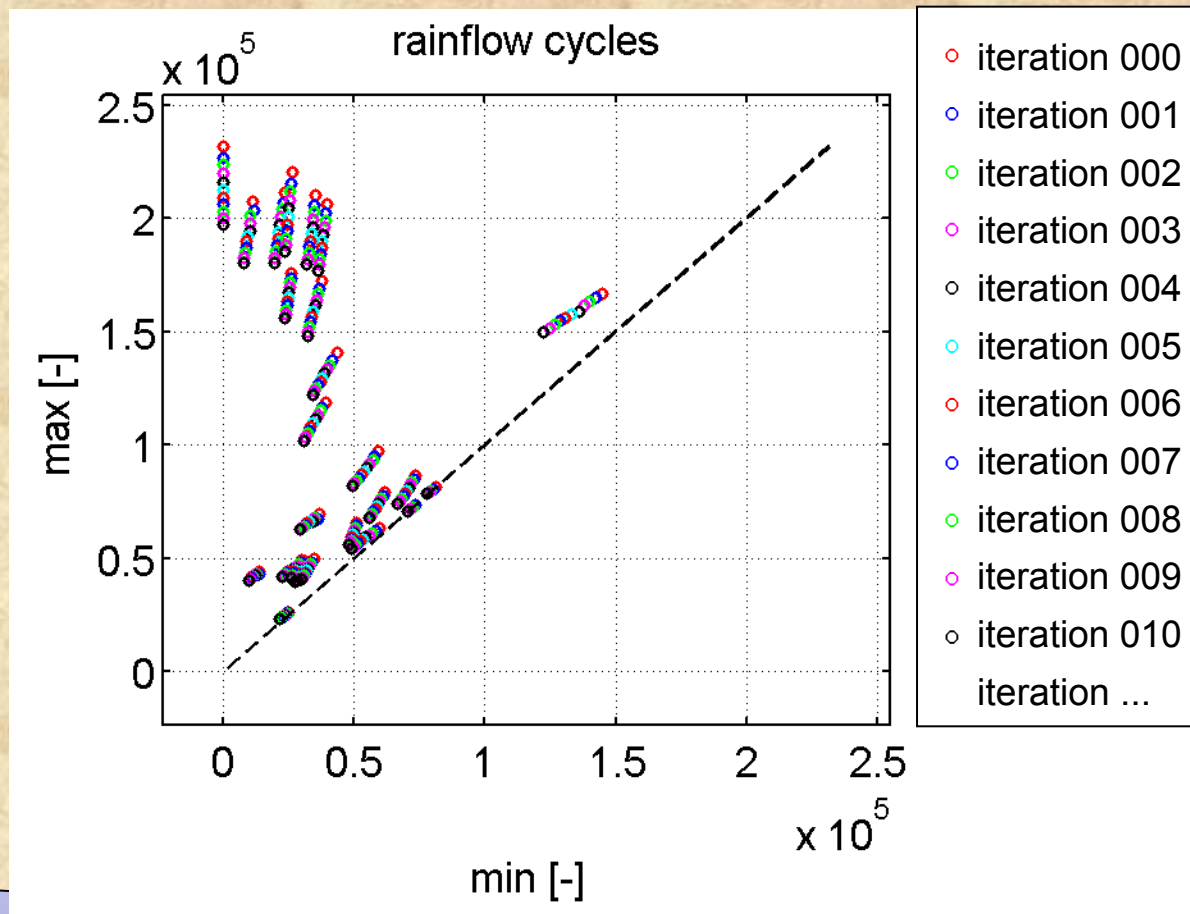
process chain



Structural optimization



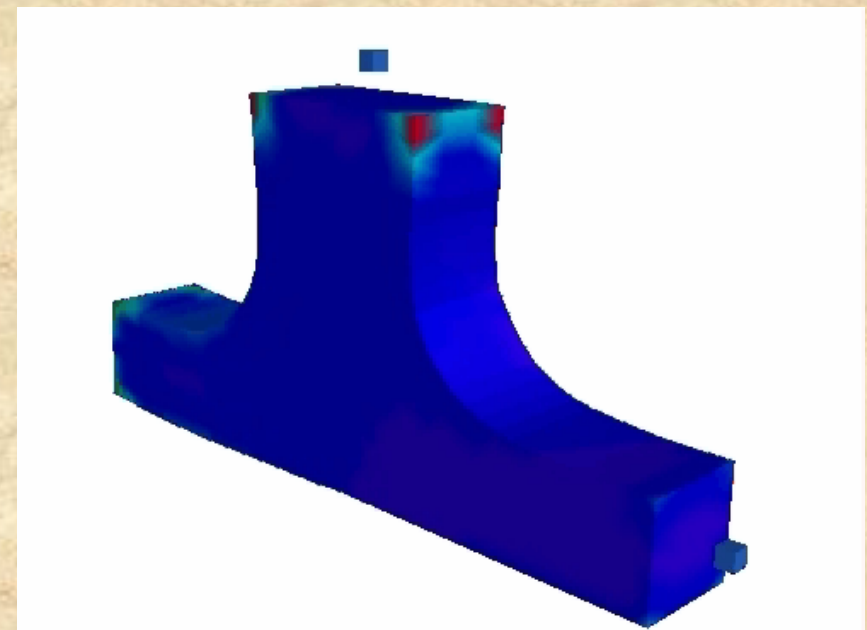
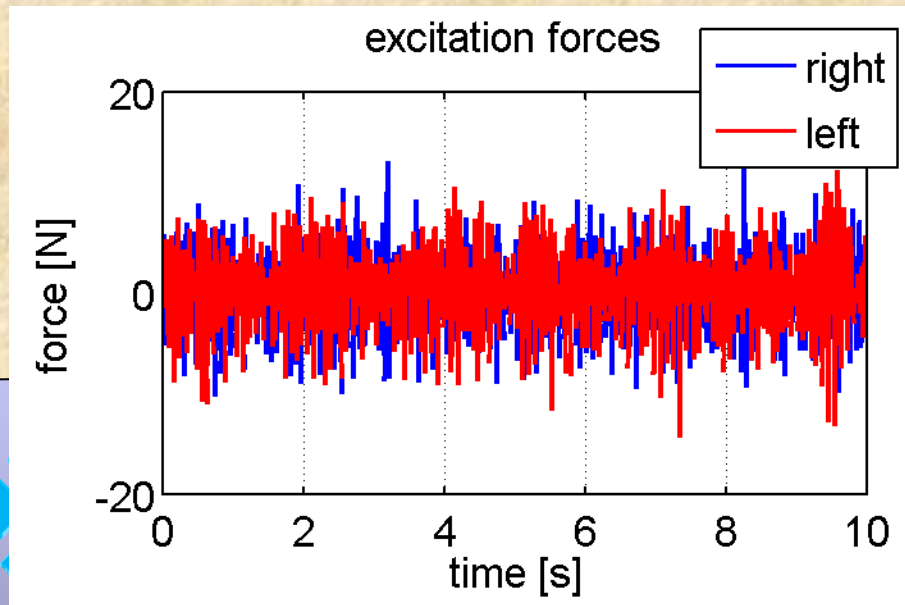
Structural optimization



Pseudo damage calculations

Idea: apply rainflow counting and damage accumulation directly on **fem-independent load channels** (e.g. applied forces)

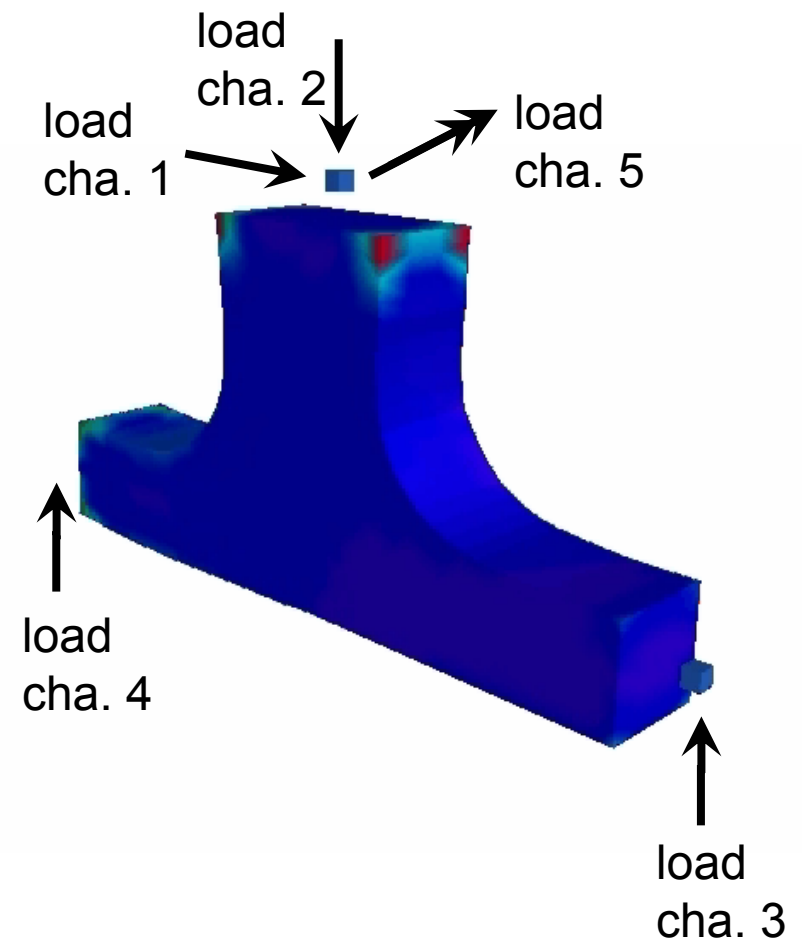
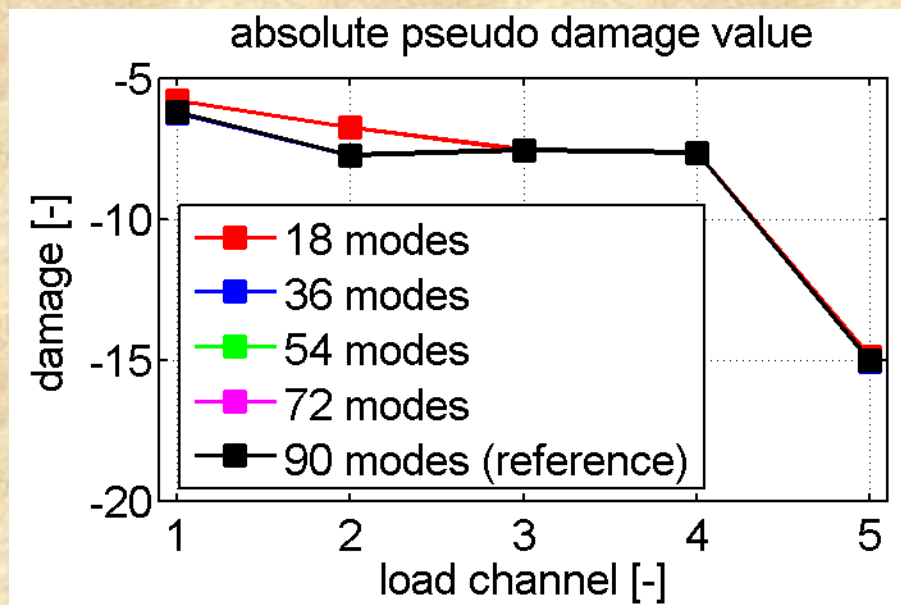
1. do rainflow counting for load channels
2. compare load hysteresis loops with a 'virtual' SN-curve
3. do damage accumulation
4. a scalar performance criterion for a fem-independent load channel in terms of durability results



Pseudo damage calculations

possible questions:

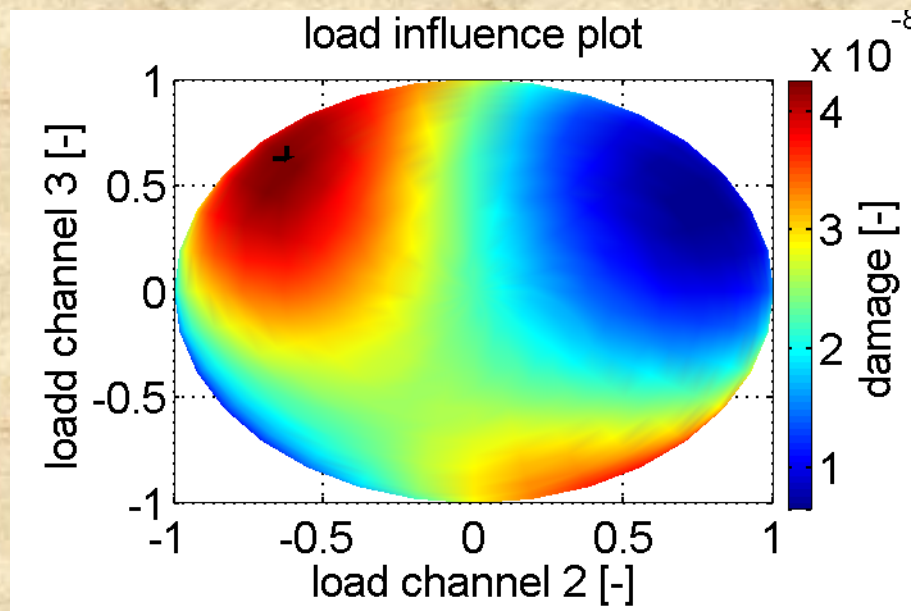
- how many modes are necessary?
- how do the load channels interact?
- does an extrapolation make sense?



Pseudo damage calculations

possible questions:

- how many modes are necessary?
- how do the load channels interact?
- does an extrapolation make sense?



$\mathbf{l}^*(t) = \mathbf{P} \cdot \mathbf{l}(t)$ where $\mathbf{P} \in \mathbb{R}^{n_1^* \times n_1}$
and $n_1^* \gg n_1$
rows of \mathbf{P} :

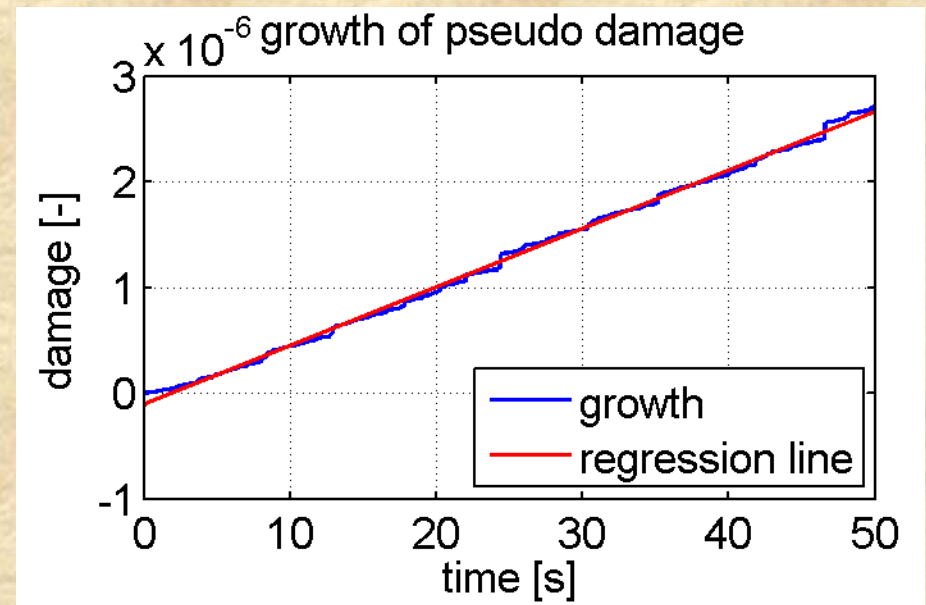
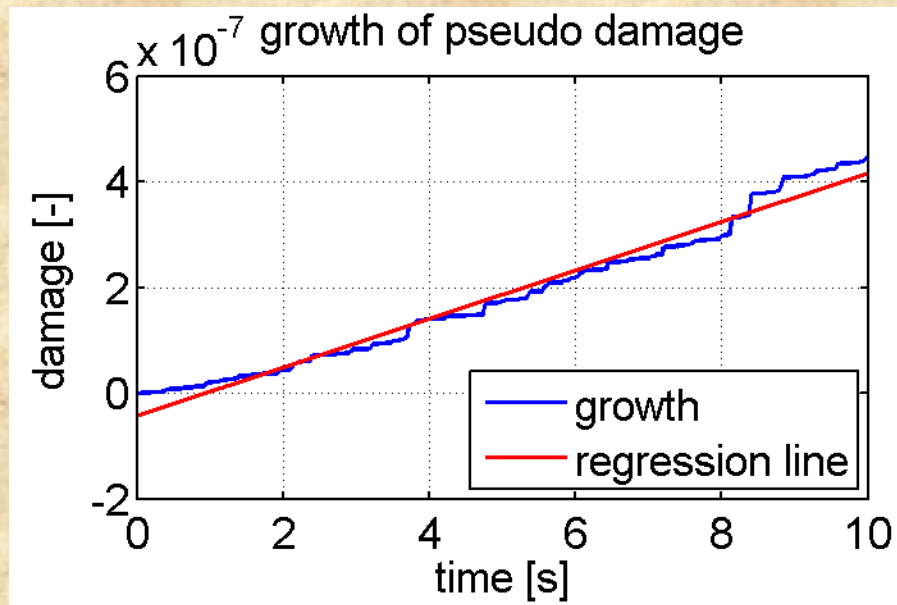
$$\mathbf{p}_i : \sqrt{\sum_{j=1}^{n_1} p_{ij}^2} = 1$$



Pseudo damage calculations

possible questions:

- how many modes are necessary?
- how do the load channels interact?
- does an extrapolation make sense?



Conclusions

1. implementation of two SIMPACK user-routines for **'online' stress** and **damage calculation**
2. results **verified** by reference calculations
3. the proposed method has **some advantages**, e.g.
 - small errors in stress
 - small result files
 - a scalar performance criterion for loads is directly outputted from the EMBS
4. some **applications**
 - structural optimization including EMBS as main tool
 - evaluation of non-fem-dependent load results with pseudo damage calculations



References

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- [Zeiss08] Carl Zeiss GmbH: *Optische Einrichtung mit einem deformierbaren optischen Element* (in German). *Prioritätsbescheinigung DE 10 2008 032 853.7*. Deutsches Patentamt, München, 2008.

